BENEATH THE BOTTOM LINE: AGRICULTURAL APPROACHES TO REDUCE AGRICHEMICAL CONTAMINATION OF GROUNDWATER

Volume II--Contract Papers

Part E: Farmer Decisionmaking

1. Farmers' Views on Groundwater Quality: Concerns, Practices, and Policy Preferences -- Steven Padgitt
2. Farmer Adoption of Conservation Practices: Lessons for Groundwater Protection -- Ted L. Napier
3. Local Agricultural Information and Assistance Networks Relative to Ground Water Protection -- Peter J. Nowak
4. Extension Education for Agrichemical Dealers Groundwater Protection: An Extension Perspective -- K. A. Kelling, J. L. Wedberg
5. Computer-Based Decision Support Systems for Farmers: Applications for Groundwater Protection -- Bernard Knezek, J. Roy Black

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FARMERS' VIEWS ON GROUNDWATER QUALITY: CONCERNS, PRACTICES AND POLICY PREFERENCES

by

Steven Padgitt
Associate Professor of Sociology and Anthropology
Iowa State University
Ames, IA

Condensed and edited by Susan J. Wintsch
Writer/Editor for the OTA assessment of
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ABSTRACT

This report descriptively reviews findings from recent sample surveys of farmer attitudes about agricultural chemicals and groundwater quality; their practices and motivations related to chemical management; and their responses to public policy alternatives addressing this issue. The studies were assembled from a review of current journals, computerized bibliographic searches, and personal contacts. Except for one national magazine subscriber survey and a national survey of adults, studies are state or sub-state based.

Substantive findings from surveys in 14 states are cited. Data could not be aggregated to draw statistical conclusions or make generalizations to the national population of farmers.

The reviewed studies document that the issue of groundwater quality is high on the public agenda of farmers. Often it was rated lower than farm profitability but generally equal to soil conservation. In the reviewed studies, farmers perceived agricultural chemicals to be a major contributor to current groundwater problems. Concerns over health and safety implications appear to equal or surpass concern for the environment. Although levels of "concern" were found to be high, farmers' perceptions about the "seriousness," of the problem, especially on their own farms, were lower. More concern was expressed over pesticide than nitrate pollution.

The studies indicate that farmers have not rigorously followed recommended nitrogen practices; nor given full credit to noncommercial fertilizer sources. Adoption of Integrated Pest Management (IPM), a program designed to more efficiently use chemical pesticides and natural controls, was found to be motivated as much, or more, by economic and health reasons as by environmental concerns. Gaps were found in farmers' knowledge of existing low-input chemical alternatives.

Those adopting low-input practices have done so for several reasons. There appears to be wide spread interest in low-input alternatives if those alternatives did not significantly alter profits. More support was found for policies that enlarge the technological choices of farmers than for those that control farm practices.

No decisive geographic patterns emerged from the reviewed studies. However, farmers with larger scale operations tended to be somewhat less interested in low-input alternatives and also indicated less support/more opposition to regulatory policy alternatives. Ideology and belief systems have been hypothesized as significant factors contributing to farmer opposition to regulation of agricultural chemicals.

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INTRODUCTION

This report focuses on the interests and attitudes of farm and ranch operators toward agricultural chemicals and groundwater quality. This segment of the population is most likely to drink groundwater should it become contaminated. Because the concentration of contaminants is greatest near the source of the pollution, they are most likely to suffer any associated health risks. Farmers and ranchers are also the ones who will be directly affected by the consequences of management decisions and public policies related to the use of agricultural chemical products.

Although this review is about farmers, threats to groundwater quality from agricultural chemicals is not just a farmer issue. Drinking water for an estimated 50 million people in the United States comes from groundwater that has the potential to be contaminated from agricultural chemicals (Nielsen and Lee, 1988).

The objective of this project was to review emerging literature on the topic by assembling recent surveys of farm populations on the use of agricultural chemicals and groundwater quality. Three major areas of inquiry are reviewed: general attitudes toward the issue, adoption of selected technologies different from high-input chemical agriculture, and preferences expressed for policy responses to the issue.

This project began with a systematic review of relevant journals and publications. A keyword search of several established bibliographic databases was then conducted to assure inclusion of more recent publications, professional papers, and agency reports. Finally, personal contacts were made by the author. The first two efforts yielded a fairly limited body of research about the issue. Personal contacts were more productive but were likely to have been less than exhaustive. The recent emergence of the issue and perhaps its narrowness accounts in part for the scarcity of published literature. Most relevant studies were conducted or reported within the last two years. None of the major studies specific to groundwater quality was more than five years old.

Substantive data from surveys in 14 states (California, Florida, Georgia, Indiana, Iowa, Massachusetts, Minnesota, Mississippi, New York, North Carolina, Oklahoma, Pennsylvania, Virginia, and Wisconsin) contribute to this review (Table 1). There is considerable variation among these states in the extensiveness of survey data.

The available studies do not cover all areas that are vulnerable to groundwater problems. Presently, more surveys appear to have been completed in cash grain producing regions of the Midwest than elsewhere. One notable gap is research from western range lands. Also, few studies were found for the southern regions. The South is an area where major potential exists for groundwater contamination and where climatic conditions heighten insect pest problems. Several of the study sites were selected because groundwater quality had become an issue of concern and public debate in the those areas. This limits interpretations for national policy.

Two studies of national scope were included. One was a study of the U.S. adult population (Center for Communication Dynamics, 1985). The other was a survey of subscribers to New Farm magazine (Data Probe, Inc., 1988); hence, its generalizability is limited to the magazine's subscriber list. Neither of the national studies had samples of sufficient size to document geographical distinctions.

The Center for Communication Dynamics study did target one state (Wisconsin) where water quality has been an issue in the press and the state legislature. This provides some insight into the effect that active local debate may have on public responses. In general, the Wisconsin sample did not vary substantially from the national sample in terms of national pollution concerns. However, Wisconsin residents were more likely to see groundwater pollution as well as sewage disposal into rivers as major national problems (58 percent versus 48 percent for the nation; 70 percent versus 59 percent for the nation, respectively). In Iowa studies of farm operators, similar discrepancies in level of concern were found between the intensively scrutinized Big Spring Basin and other regions in the state (Padgitt, 1987). These findings suggest media attention contributes to or is a reflection of heightened awareness and concern.

Four sections follow. The first is a summary of farm population attitudes with occasional references to non-farm populations. Most farm studies used the "farm operator" as the respondent. This often results in the respondent being an adult male. The second section examines selected farm practices and alternative approaches to the use of agricultural chemicals. This section also summarizes reasons farmers give for adopting these practices. The third section examines reactions, obtained from the survey literature, to selected policy options. The report concludes with a short summary and discussion section.

An appendix has been compiled to summarize findings from the diverse studies in a straightforward manner. Information about study populations, dates, sample size, and data collection methods are included. Also, a brief statement of findings and comments on generalizing from them is presented.

SURVEY FINDINGS ON ATTITUDES TOWARD AGRICULTURAL CHEMICALS AND GROUNDWATER QUALITY ISSUES

Many studies identified for this review focus on local situations or problems. Often the studies were descriptive in nature rather than strictly hypothesis testing. As a result, it is neither appropriate nor possible to aggregate these local and regional studies into a larger framework. One exception is a coordinated data set by Esseks (1988a, 1988b). It has identical measures from five counties in five states. Those study sites were geographically dispersed and agriculturally varied. Specific locations were selected because agricultural chemicals had been documented in local groundwater.

Fortunately, a few investigators have shared survey instruments. In those cases, some comparisons can be made for descriptive purposes, and certain findings are remarkably similar. Statistical procedures have varied. In this review the use of the term "significance" will be restricted to occasions where more rigorous statistical probabilities were used to draw conclusions about relationships.

In reviewing the attitude studies it is important to keep in mind that the findings represent subjective assessments of respondents, not objective indications of environmental risk. The extent to which perceptions reflect actual contamination or threats to the environment is largely undetermined. Partially, this is because of an absence of objective data. Concentration standards exist for some compounds, but certainly not for all about which the public has concern. Variations in natural environmental conditions, farming activities, and other factors also affect risk.

Importance of water quality as a social issue

Several surveys of farm populations as well as of the general public have documented the importance given water quality. One procedure has been to ask respondents to rate or rank a series of issues. Rather than begin with questions about groundwater and agricultural chemicals[1], several researchers first introduced broader issues of water quality and then narrowed the focus to groundwater and finally to the issue of agricultural chemicals.

Findings from farm population studies in Iowa (Iowa Department of Natural Resources, 1986; Lasley, 1988; Padgitt, 1987,1988a, 1988c), as well as Minnesota (Downing et al., 1988) and Virginia (Halstead et al., 1988a), provide clear evidence that surveyed farmers in those locations attach a great deal of importance to drinking water quality (Table 2). The general, but not exclusive, pattern has been for water quality to be rated as slightly less important than profitability or economic well being. Often, the importance assigned to water quality and soil erosion issues has been similar.

Lasley's (1988) study illustrates how critical question wording can be in research attempting to rank the importance of different issues. His list did not include "water quality," but more specifically "presence of pesticides, herbicides and other chemicals in drinking water," and "contamination of underground water supplies." On his 7-point scale, the drinking water item had a mean of 6.1 and ranked third among 19 issues. The groundwater contamination item had a mean of 5.7 and ranked ninth on the list. The difference between the two was statistically significant (additional analysis by author).

Data from several studies, including Lasley's and Anderson's (1988) of North Carolina farmers suggest that agricultural chemicals and groundwater quality receive greater importance when posed as health issues rather than environmental ones. A recent four state survey (Iowa, Washington, New York, and North Carolina) by Donham (1988) focusing on broad issues of agricultural health found high priority assigned to agricultural chemicals in drinking water. Padgitt (1988c) reports from his Iowa studies that attitudinal relationships between water quality and agricultural health are quite strong, more so than correlations between water quality and other environmental issues such as soil conservation.

The Perceptual link between Agricultural Chemicals and Groundwater Quality

Although some of the studies cited above did not highlight agriculture, or agricultural chemicals in particular, as a threat to water/drinking water quality, others have firmly established that pesticides and fertilizers are perceived as such by both farmers and the general public.

In a statewide survey by the Des Moines Register (Pins, 1986) just over half of the adult population in Iowa (52 percent) identified farm chemicals as the greatest threat to drinking water in the state. Industrial waste was cited by 38 percent. Another survey of the same population (Iowa Department of Natural Resources, 1986) asked what they felt were the main sources of most groundwater pollution in the state--an open-ended question. Sixty-three percent of all respondents and 67 percent of farmer respondents answered agricultural chemicals. Industrial and manufacturing sources were the second most frequently mentioned category, but were identified by a mere 16 percent of all respondents and 18 percent of farmers. In subsequent questioning, perceptions about 10 alleged sources of groundwater contamination were systematically collected. Again, farm pesticides were the source identified most frequently as contributing "a great deal of pollution." Sixty-seven percent of all respondents and 52 percent of farm respondents gave this response (Table 3). Among all respondents, including the farmer subset, farm fertilizers ranked second. Hazardous waste ranked third among all respondents and fourth among the farm household subset. Among farmer respondents, landfills and abandoned dumps and hazardous waste disposal were viewed as having about equal importance as farm fertilizers as a pollution source.[2]

In several other studies, agricultural chemicals were identified, at least indirectly, as a major contributor to groundwater problems. For example, studies in Virginia (Halstead et al., 1988), Minnesota (Downing et al., 1988), Iowa (Padgitt, 1987) and Oklahoma (Moore, 1988b) solicited responses to one or both of the following two statements:

a. So little pesticide residue ever enters the groundwater that it could never pose a health risk for humans.

b. Water quality is more of an issue for the future, today the threat from agricultural chemicals is quite small.

By large percentages, respondents disagreed with these statements. In the four farmer samples, "disagree" answers to the first statement ranged from 80 to 89 percent. In the three farmer samples given the second statement, "disagree" answers ranged from 69 to 72 percent.

Interestingly, if a bias exists in the question wording it would tend to solicit less not more concern. Both statements provide a rationale for downplaying the importance of the concern.

Greater health concerns have been expressed for pesticides than for nitrates (Padgitt, 1988a), especially when farmers were asked to rank one over the other. In one study (Padgitt, 1988a) the ratio was 30 (pesticides) to one (nitrates). Where ratings were solicited for several categories of agricultural chemicals, the same pattern emerged, but less distinctly. There has been slightly greater concern expressed over insecticides than herbicides.

Proximity of problem and attitudes toward agricultural chemicals and groundwater quality

Findings reviewed thus far quite consistently suggest that farmers consider on-farm use of agricultural chemicals to be a major contributor to groundwater pollution. Upwards of 80 percent of farmers in the Downing et al. (1988), Halstead et al. (1988a), Moore (1988b), and Padgitt (1987) studies responded that they "worry" about the purity of drinking water. However, belief that one's own water supply was not unhealthful has persisted in the farming and general population. This was explicitly shown in Pins' (1986) study of the general population in Iowa, and is consistent with an earlier statewide Iowa farmer study (Lasley, 1984). In both of those studies the tendency was to view drinking water problems as more serious for the "other guy"--people in other communities or states.

Similarly, Iowa farmers assigned greater seriousness to water problems problems in the nation and state than they did to those in their own county or on their own farms (Padgitt, 1988b). The difference was fairly dramatic. The "very serious" rating was 40 percent for "in the nation" and eight percent on "one's own farm." (Conversely, the "not at all serious" rating was two percent for "in the nation" and 37 percent for on "one's own farm.")

Recent evidence by Esseks (1988a) lends credence to the proximity pattern in environmental assessments. Although Esseks asked different questions about national, county and on-farm settings, problems were judged less serious as proximity increased. Esseks found this pattern in five diverse areas: Lancaster County, Pennsylvania; Jackson County, Florida; Portage County, Wisconsin; Cherokee County, Iowa; and Stanislaus County, California.

The tendency to deny a problem exists close to home has been documented in numerous other contexts. Farmers tend, for example, to deny soil erosion on their own land. On the other hand perception of health risks from agricultural chemicals seem not to follow this pattern. Four separate Iowa studies as well as the Minnesota and Virginia studies asked respondents how concerned they were that the "use of agricultural chemicals (fertilizers and pesticides) posed a health risk to people." Four referent categories (in the nation, in one's state, in one's county or region, and on one's own farm) were used with minor variations. In none of the studies was a significantly lower level of concern expressed as proximity increased. Quite high and consistent levels of concern were expressed in each of the studies (Table 4).

"Concern" rather than "seriousness" was the keyword in these studies, and it is not clear whether the difference in the answer pattern stems from this distinction or from the direct focus on health versus the indirect environmental implications of the other studies. One interpretation is that "concern" elicits a higher affirmative response than "seriousness", and the health link accounts for sustained concern with increased proximity.

Cost-Benefit and Environmental Risk Attitudes

Although recent attitude studies document that farm populations perceive agricultural chemicals with much concern, chemical use remains widespread (Lockeretz and Wernick, 1980; Nielsen and Lee, 1987; U.S. Department of Agriculture, 1983). This would appear to indicate conflict in the private lives of farmers. Several lines of questioning have been used to document this condition.

There is evidence many farmers--upwards of 80 percent of those polled in two Iowa studies (Padgitt, 1988a, 1988c)--would like viable alternatives to farm chemicals. This was also a major message from a statewide study of New York farmers (Buttel and Gillespie, 1988). On the other hand, there is little evidence that the conventional agricultural community is ready to abandon chemicals on short notice. Indeed, studies among largely row crop grain farmers have found the majority believe pesticides are their best current alternative to control weeds, pests and plant diseases. In Wisconsin, an agriculturally diversified state, the reason farmers most often identified for not reducing chemicals was their belief they had already reduced them as much as they could (Wisconsin Rural Development Center, 1989).[3] Esseks (1988a), likewise, found between two- and three-fifths of farmers believed they had already found economical ways to reduce chemicals.

Esseks, the Wisconsin Rural Development Center, and Padgitt all found a perception among most farmers that their enterprises would be less profitable if they used fewer commercial chemicals. In Esseks' five county/five state study, this ranged from a low of

65 and 66 percent in Iowa and Wisconsin to a high of 80 percent in Florida. Between one-fifth and one-third of surveyed farmers felt profitability would not be reduced. In the statewide study of Wisconsin farmers (Wisconsin Rural Development Center, 1989), 71 percent of the respondents felt their yields would drop if chemical inputs were reduced. When a hypothetical framework of a herbicide ban was posed to Iowa's corn farmers, there was nearly a universal belief that yields would decline (Padgitt, 1988c). Additionally, half of the farmer respondents felt input costs associated with increased tillage, labor, and machinery would more than offset savings from herbicide reductions. The differences among the Esseks, Wisconsin Rural Development Center and Padgitt findings were likely due to differences in question format, context, and in the dominant kinds of agriculture practiced by respondents. Padgitt's context was a herbicide ban while Esseks and the Wisconsin study sought responses to an incremental "use of fewer chemicals."

More polarized attitudes emerged, however, when Padgitt (1987, 1988a), Halstead et al. (1988a), Downing et al. (1988), and Moore (1988b) sought agree/disagree responses to the following: "I am confident that agricultural pesticides, if used as directed, are not a threat to the environment." Generally, fairly even splits were found between those agreeing and those disagreeing.

Divided opinions also emerged over several items in a random sample of New York farmers (Buttel and Gillespie, 1988):

a. The pollution effects of nitrate fertilizers are quite unimportant compared to all their benefits (agree = 23 percent, neutral/uncertain = 32 percent, disagree = 45 percent).

b. There is too much talk about all the harmful effects of pesticides and not enough about their benefits (agree = 40 percent, neutral/uncertain = 22 percent, disagree = 38 percent).

c. Environmentalists have greatly exaggerated the dangers of nitrate fertilizer pollution (agree = 30 percent, neutral/uncertain = 42 percent, disagree = 28 percent).

In summary, farmers seem to approach and justify their use of chemicals from an economic decision making framework. When doing so, rather strong endorsements are found. When asked to consider health and environment issues as part of chemical use, a more divided response pattern emerges.

Relationships between Attitudes and Independent Variables

Most, but not all, of the studies cited have attempted to relate attitudes to personal and farm operation characteristics, or have used other comparative groups to help understand and account for differences in attitudes. In general, personal characteristics such as age and education were found not to be strong predictors of how farmers answered attitude questions about agricultural chemicals. This was reported by Buttel et al. (1981) in a study of New York and Michigan farmers. More recently, Esseks (1988a and b) found just two significant relationships in 10 comparisons between farmers' perceptions of the need to have water tested and education. In Iowa studies (Padgitt, 1988a) found two weak, but persistent, patterns: older farmers and farmers with less education expressed slightly more concern about groundwater issues; and farmers with larger acreages in the Iowa studies tended to express slightly less concern about groundwater quality issues. The latter finding is consistent with, but perhaps the relationships not quite as strong as, the generally inverse relationship Buttel et al. (1981) found between agricultural scale/wealth indicators and environmental concerns.

Anderson (1988) categorized farmers by the intensity of their synthetic-chemical use. In a sample of North Carolina farmers, she found significantly different responses to only three of 18 concerns[4] about using agricultural chemicals: whether the product might be harmful to birds or other wildlife; cost of the product; and whether the agricultural extension agent recommended the product. Full-time farmers with more synthetic-chemical intensive operations expressed less concern about wildlife than farmers with less chemically intensive operations but more concern about cost and whether a product was recommended by an agricultural extension agent. Both farmer groups shared similar concerns over the effects of agricultural chemicals on personal and family health and groundwater quality.

In a similar vein, Halstead et al. (1988b) explored differences in attitudes between farmers with high and low levels of nitrogen fertilizer use. Their analysis included both inorganic and organic sources of nitrogen. Statistical tests revealed that high appliers were less concerned about contamination on their own farms than were low appliers. The pattern held for both Rockingham County, Virginia and the Big Spring Basin in Iowa. Significant differences also emerged in several attitudinal measures (five of 14 in Virginia and three of five in Iowa). These revealed that high appliers consistently saw agricultural chemicals as less of an environmental problem than low appliers.

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Comparisons between farm and nonfarm segments of the population have also been made and these invariably show that attitudes of nonfarm respondents reflect more environmental concern. This is consistent with previous studies about other environmental issues. In contrast to their nonfarm and urban counterparts, farmers have tended to be less aware of and less concerned about environmental issues (Buttel et al., 1981; Trembly and Dunlap, 1978; Van Liere and Dunlap, 1980). Buttel et al. (1986) go so far as to conclude that U.S. farmers are in the aggregate, among the most anti-environmental of major occupational groups.

This may be a bit strong given the kinds of evidence produced in the cited studies. Persons with vested interests in the status quo seldom advocate change; consequently, the major surprise may be the extent of concern about groundwater quality by farmers, not the extent to which they differ from nonfarmers (Padgitt and Hoyer, 1987). The more direct health implications of this issue, in spite of denial or nonrecognition of problems on one's own farm, may be a factor distinguishing it from other environmental issues.

Implications for policy

These findings of farm operator views about agricultural chemicals and groundwater quality contain several implications for public policy. If a problem is unrecognized, corrective changes cannot be expected with mere passage of time. If a problem is recognized, then its consequences are likely to be interpreted in several contexts before possible corrective action occurs. In the case of groundwater quality, such factors as consequences for the health of one's self and family, beliefs about general environmental degradation, and assessment of farming practice alternatives (including their availability, impacts on agricultural operations, and profitability) would be important. Additionally, the power, control, or freedom that farmers have to make changes would affect the likelihood of change.

Several of the studies reported upon here were conducted because of some previous attention to a problem or potential problem, and the evidence suggests that farmers have not been surprised by presence of agricultural chemicals in groundwater. In short, there is general awareness of a problem, and farmers express concern about health effects. They also recognize other sources of groundwater contamination, but this has not displaced general concerns about farm chemicals in groundwater.

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There seems to be a lack of motivation for personal action, in part, perhaps, because farmers do not acknowledge a serious problem on their own farms. This may be denial or it may be genuine nonrecognition. Whichever, in the absence of specific knowledge about one's own drinking water or documented health problems attributable to groundwater contamination, voluntary change is not likely to occur quickly or on a widescale basis. On the other hand, if the problem is genuine nonrecognition, education and interpretation could have an important impact. Farmers have reported such evidence would be motivation for them to change. Many private wells are not regularly tested, especially for pesticides. A policy of monitoring would seem to be in the public interest, and if findings warrant, perhaps sufficient to prompt attitude and behavior change.

Another impediment to voluntary change may be beliefs or knowledge about alternatives. Survey evidence indicates that farmers have an open mind about the use of agricultural chemicals, i.e. they would consider alternatives. At present, however, they believe pesticides are their best allies against insects, weeds, and plant disease; and that they have already reduced their chemical inputs as much as they rationally can.

Monitoring attitudes is important if we are to anticipate reaction to policy alternatives. By fostering attitude change it may be possible to encourage change in farming practices and this is a policy alternative. There are implications in the surveys that general attitudinal orientations are important precursors to behavior. Farmers appear to be open minded, but are not fully convinced of the true seriousness of the problem or of the viability of current solutions. There does not appear to be a groundswell among conventional farmers for labor intensive or confining alternatives.

Farmers are suspicious, but uncertain, about the true health risks associated with agricultural chemicals. More definitive evidence in either direction will likely have considerable impact on attitudes and voluntary approaches to farming. This is a reason for public policy to support increased research. The validity of differences between perceptions about nitrates and pesticides may need additional attention. "Mere" traces of compounds in groundwater has not become a major motivator for change among large scale conventional farm operators.

SURVEY FINDINGS ON FARMERS' PRACTICES THAT MAY AFFECT GROUNDWATER QUALITY

Because a full inventory of agricultural practices is beyond the scope of this review, the focus will be on a few selected practices, particularly those related to row crop production. The section relies mostly on studies reviewed in either the preceding section on attitudes or the following section on policy. Any findings related to motivational reasons for adopting or not adopting a certain practice are included here.

A national impact evaluation of Integrated Pest Management (IPM) programs commissioned by the Extension Service (USDA) and conducted by the Virginia Cooperative Extension Service (Rajotte et al., 1987) is also drawn upon, as are selected surveys of farm operators who consider themselves, or who have been labeled by others, "organic" or "alternative agriculture" farmers[5].

Awareness of and adherence to recommended practices regarding nitrogen management in corn production

Nitrogen is an essential and naturally occurring plant nutrient, but its use in inorganic form has played a major role in increased yields of grain. The use of commercial nitrogen fertilizer is nearly universal in U.S. corn production (U.S. Department of Agriculture, 1983).

Although there is growing controversy about the amounts of nitrogen farmers need and over whether levels currently recommended by land grant universities will be the recommended levels of the future, a more immediate issue may be the extent to which current recommendations are followed. Of three recommended management practices to minimize leaching (basing nitrogen application rates on realistic yield goals, crediting nitrogen contribution from sources other than commercial nitrogen, and applying nitrogen at times when plant needs are greatest) survey findings in Iowa indicate none are being stringently followed.

The Iowa studies indicate farmers do have yield goals and use multiple criteria for establishing them. On average, yield goals were about 10 percent higher than harvested yields. Highest historical yield is the most widespread criterion for setting yield goals (56

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percent). Corn suitability ratings (CSR), a scientific criterion generated from soil surveys and agriculture research, and germ potential of seed stock were each cited by about one-fourth of the farmers.

Yield goal is one of several factors farmers use in determining nitrogen rates. Its use (61 percent of farmers) was less than on-farm experiments (80 percent of farmers), but slightly more than fertilizer dealer recommendations (50 percent of farmers). When nitrogen rates were checked against reported average yields and compared with the state's land grant college's recommended rates, one-fourth of the farmers were exceeding the recommendation by 25 pounds of nitrogen of acre or more (Padgitt, 1988b).

There was also evidence that farmers did not fully adjust for nitrogen available in animal waste, nor for nitrogen residuals in rotation from legumes or soybeans to corn (Halstead et al., 1988, and Kaap, 1987). The Iowa studies have shown that up to 40 percent of livestock farmers took no nutrient credits at all for manure, and over half took no nitrogen credits. Kaap (1987) found that when farmers take nitrogen credits in rotating fields from alfalfa to corn, they generally take less than recommended levels.

Kaap's (1987) analysis for the Big Spring Basin, a fairly intensive livestock and grain area, found that if best manure management practices were followed and full credit was given to organic sources of fertilizer (including phosphate and potash as well as nitrogen) these sources yielded an economic value of approximately $3,500 per farm. (This was emphasized in Extension programs in the basin; two years later a follow-up study found 40 percent of farmers cutting back on nitrogen applications.)

Recommendations about the timing of nitrogen applications are also made. Fall nitrogen applications are discouraged because of increased probability of leaching into groundwater before plant uptake in the next growing season. The extent to which nitrogen is applied in the fall is thought to vary widely. Studies in three regions of Iowa found this practice was not widespread (12 percent or less of farmers).

"Sidedressing" is a practice that brings nitrogen to plant roots at a time of rapid growth, and "other things being equal" it helps to minimize leaching. But, sidedressing requires another equipment pass across the field. The recent Iowa studies have shown infrequent use of sidedressing (generally less than 10 percent of farmers). When used, it has sometimes been a remedial rather than a planned practice.

Integrated Pest Management

IPM is a system of pest control encompassing a variety of techniques and methods that are both environmentally sound and compatible with farmers' existing practices (Rajotte et al., 1987). A basic principle of IPM is monitoring pest populations, or "scouting". Corrective actions are based on economic threshold analysis. These include chemicals, biological agents, cultural practices, resistant host plants, trapping techniques, etc. IPM has the potential to reduce the amounts of harmful compounds introduced into the environment (Hallberg, 1987). For example, if insecticides are applied when insects are most vulnerable, smaller amounts of chemicals may be needed. Also, by selecting crop varieties resistant to pests, rotating crops, adjusting planting dates, and maintaining habitat for beneficial species, fewer synthetic materials should be required to control pests.

Others believe, at least for certain crops and at initial levels of adoption, IPM could increase the use of chemicals, especially insecticides (Grundman, 1988). Through scoutings, for example, farmers may learn about and treat infestations they otherwise would not notice.

As background to their major national study of IPM adoption, Rajotte et al. (1987) reviewed empirical studies showing that, in general, IPM reduces pesticide use, increases yields, increases net returns, and decreases economic risk. They cite findings from 35 studies involving 10 crops that showed IPM lowered pesticide use and/or cost of production. Because some of these studies used research plot or demonstration project data to make projections and draw conclusions, there may be variances at the farmer level of adoption. Rajotte et al. (1987) conducted case study surveys in 16 states involving nine agricultural commodities.[6] Scouting was found to be the most pervasively adopted IPM technique, although a large percentage of respondents reported other crop-specific IPM practices. The investigators used scouting as the major criterion to distinguish IPM users and nonusers. Like the other studies they cited, their impact study found, in general, higher gross revenues and net returns among IPM users (Table 5).

Actual levels of pesticides use were not reported. This is understandable given the difficulty and expense of collecting reliable on-farm chemical use data. However, indirect indicators suggest IPM did not universally lead to less pesticide use when scouting was the criterion for IPM adoption. For example, the national assessment's study of Indiana corn producers found IPM users made more insecticide and herbicide applications per year than did nonusers. They may have used lower application rates because of timing or other factors, but this is questionable because total pesticide costs for IPM users were also higher. A similar but less distinct pattern was found among Virginia soybean producers. Cotton producers using IPM in both Texas and Mississippi reported on average, considerably higher insecticide costs than did nonusers. Similarly, almond producers in California identified as IPM users appeared to be more dependent upon chemicals than nonusers based on amount of spraying, fumigation, and use of herbicides.

On the other hand, apple producers in New York and Massachusetts using IPM reported lower total pesticide costs. Peanut growers from Georgia using IPM had lower pesticide costs per acre. Tobacco growers in North Carolina using IPM made fewer applications per year, although their costs were not lower than nonusers.

Farmers in the multistate study strongly endorsed IPM whether or not they used it. In general, the most important "selling points" cited were improved pest control, increased crop yields and quality, increased returns to management, protection of personal and public health, and reduced environmental damage (Table 6). IPM users assigned slightly more importance to all of these selling points than nonusers. Comparisons of users and nonusers suggest that IPM follows a somewhat traditional model of adoption. That is, users were likely to be more educated and younger; to have larger farming operations; and to depend more on technical sources of information.

Without question, IPM has major potential for strengthening environmentally sound practices. A number of measures are already available and new knowledge promises additional alternatives. For now, however, IPM adoption may carry some of the same limitations that conservation tillage has experienced as a solution to soil erosion problems. Just as discontinuance of the moldboard plow did not end soil erosion, systematic scouting for pests may not always translate into increased groundwater protection through reduced pesticide inputs. In both situations farmers may utilize some features of alternative technologies to reap economic benefits, but decline to pursue the more detailed and perhaps more managerial difficult refinements needed to more fully protect the environment.

Practice Adoption and the Alternative Agriculture Movement

For at least a decade, a grass roots movement ambiguously referred to as "alternative agriculture", "sustainable agriculture", "organic agriculture", and "low input agriculture" has developed (Youngberg, 1978). As with all beginning movements, it has been somewhat amorphous, and there is not a complete ideological consensus among its adherents. Many of

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those who identify with the movement experiment with and seek new ways to reduce chemical inputs. This prompts occasional scoffs from conventional farmers, who caution such approaches would be unprofitable if widely adopted in today's market system and would not produce the needed supply of food. This section does not address the economic or production issues; rather, it explores findings from surveys that compare the characteristics of persons identifying with alternative agriculture with profiles of the general farm population.

Recent publications by Buttel and Gillespie (1988), Data Probe, Inc. (1988), and Anderson (1988) provide important insights. Like previous sociological studies (Contant, 1988; Dalecki and Bealer, 1983; Foster and Miley, 1983; Harris et al., Lockeretz and Wernick, 1978; Vail and Rozyne, 1980), Data Probe's New Farm survey tends to debunk stereotypes of adherents to this movement (Table 7). It found highly educated farmers with substantial investments and commercial enterprises among the magazine's subscribers. Although very few (five percent) identified their operations as chemically intensive, only about one-fourth had eliminated use of chemicals. Like other studies of the low input adherents, the New Farm study found that its subscribers were farmers who had used more chemical inputs in the past.

Of those who had recently cut back on chemicals, 66 percent reported no change in income, and 27 percent reported an increase. Answering why they were cutting back, they cited environmental concern, health and safety reasons (68 and 67 percent, respectively), and production cost reduction (Table 8). In fact, among mostly cash grain producers, cutting production costs was a more dominant reason (81 percent) than either environmental concern (64 percent) or health and safety (56 percent). This is consistent with findings by Buttel et al. (1986), Gersh (1988), and Anderson (1988) that organic and reduced-input farming was more often adopted to solve particular production, livestock, or human health problems, than for ideological reasons.

Buttel and Gillespie's (1988) more recent study of New York farmers suggests that large numbers of conventional and commercial farmers may have interest in adopting more resource conserving, environmentally sound and reduced-input practices than has heretofore been recognized. They presented a sample of New York farmers with dichotomous alternatives for eight phases of crop production. Before being asked which they preferred, farmers were told to assume that the alternatives described would yield about the same net profit.

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Preference for the lower input/more environmentally sound alternatives (Table 9) varied from 86 percent (seed varieties with moderate yield, high pest resistance) to 36 percent (more labor, less purchased products). In a comparison between small and commercial farmers (determined by gross farm sales and a $40,000 break point), statistically significant differences were found in four of the eight areas of production covered. For three of these (weed control, crop rotation, lower purchased inputs) small farmers were more likely to select the lower input option. For one (as few tillage operations as possible), commercial farmers more often chose the low-input option.

Although the Buttel and Gillespie study unmistakably documents widespread interest in the lower input and more environmentally sound alternatives, it is important to keep in mind that farmers responded under the assumption of no impact on yields or net profits. Experiences of New Farm respondents adopting reduced chemical inputs tend to validate the credibility of this assumption; however, other research (Esseks, 1988a; Padgitt, 1988c; and Wisconsin Rural Development Center, 1989) casts doubt on whether most farmers would accept this premise. Perhaps, the more important message, as is emphasized by Buttel and Gillespie, is that potential and substantial interest exists among a broad population of farmers. They also highlight a need to reconsider the current research agenda so that these technologies can be developed or refined as viable alternatives.

Implications for policy

Survey findings indicate farmer interest in alternatives to chemically intensive agriculture, but suggest that a number of farmers are not taking full advantage of existing recommendations and technologies to alleviate groundwater problems, particularly those associated with nitrogen management. The potential of educational programs to reduce nitrogen application in corn production deserves greater attention. Despite controversy over crop needs and recommended rates, there appears to be some opportunity for many farm operators to simultaneously increase profit and improve groundwater quality. Whether rigid adherence to recommended rates and crediting noncommercial sources of nitrogen would be sufficient to protect groundwater from excessive nitrate is undetermined. Evidence has been gathered that farmers are already rethinking nitrogen practices in areas receiving attention. Educational programs and on-farm demonstrations would further nurture voluntary reduction in nitrogen.

The impact of IPM on levels of chemical use is speculative. For some crops (most notably apples in the reviewed surveys), it seems IPM has resulted in decreased dependence upon chemicals, but conclusions are less convincing for some of the other crops. There are, however, some important factors favoring support of IPM if voluntary change is an objective of public policy. IPM adoption, at least at the first level, is already occurring among large scale conventional farmers. These are farmers who, traditionally, have been more dependent upon pesticides. Because this group comprises a large proportion of the farm population and is responsible for most of the pesticides applied, gaining their confidence and interest is critical. IPM appears to have accomplished this, and now aspects of it other than scouting have potential for adoption.

The recent documentation of widespread interest among conventional farmers in low-input alternatives suggests that investments in research and education to foster adoption of more environmentally sound practices has promise. The strength of this interest among conventional farmers strongly challenges assumptions that farmers prefer high-input chemical agriculture.

SURVEY FINDINGS ON FARMERS' PREFERRED POLICY RESPONSES TO THE ISSUE OF AGRICULTURAL CHEMICALS AND GROUNDWATER QUALITY

As public awareness of groundwater vulnerability has increased, so have concerns that government "do something." Previously, water policies have focused more on drinking water standards, surface water, point sources, industrial contaminants, etc. The realm of agricultural chemicals and groundwater policy is relatively new, but the policy options are many. Abdalla (1987) identified several that are being pursued at state levels: strong regulatory roles (e.g., California and Wisconsin), public expenditures (e.g., Massachusetts), and research, education and demonstration (e.g., Iowa). Esseks (1988b) suggests viewing agricultural chemical and groundwater policy as a continuum of options. One end is defined as enlarging the technological choices open to farmers and the other by controlling farmer behaviors. Along the continuum exist such policy alternatives as basic research to create new alternatives, applied on-farm research, education programs, monitoring programs, economic incentives and disincentives, and regulatory control and enforcement. Although a full array of data are not available, farmers tend to support policies that increase technological choices more than options that control farmers' behaviors. These findings come mostly from those studies discussed earlier which report various policy preferences.

In the paragraphs that follow, survey findings are organized under several policy options used as topical headings. With the exception of Esseks' study (1988b), most surveys appear to have included policy items for secondary, descriptive, or exploratory reasons rather than for systematic policy analysis.

Care must be exercised in interpreting responses to hypothetical policy items. At best, they are a pulse of initial reactions. Levels of support and opposition can shift dramatically as proposed policy becomes articulated and social action starts to intensify. Likewise, the manner in which policy is implemented can affect the public's reception of a policy. Cross compliance aspects of the 1985 Food Security Act are a case in point. Lasley (1984, 1988) has monitored Iowa farmers' reactions to requirement for approved conservation plans on erodible land as a prerequisite for eligibility in federal farm programs. As this policy has become law and dates for compliance have neared (along with some lessening of compliance criteria) farmer support for the policy has dropped, at least somewhat.

Enlarging the technological choices through research and education

Public agencies are criticized at times for not giving sufficient priority to research and educational programs geared toward developing and demonstrating viable alternatives to chemically intense farming practices. Additionally, the credibility of alternatives emerging from on-farm research is questioned.

Buttel and Gillespie (1988) have found widespread interest in low-input environmentally sound technologies, at least when presented to farmers in an equal profit framework. The Wisconsin Rural Development Center (1989) found a majority of farmers unsure how to apply alternative practices to their farms.

In direct questioning, Esseks found federal funding for research and education in low-input technologies to be a popular policy option. Across his five county/five state sites, support for research ranged from 72 percent in California to 91 percent in Florida. Technical support to farmers to reduce the use of chemicals, received equal or slightly more support -- from 80 percent in California to 92 percent in Florida. In posing the question, Esseks explicitly stated an optimistic consequence of funding the research (e.g., it should help reduce the possibility of contaminating groundwater as well as benefit farmers financially by lowering their costs of production).

When Esseks' respondents were asked whether farmers would *use* free technical assistance, there was a meaningful, but not precipitous, drop in interest. Between 57 percent (Wisconsin) and 64 percent (Iowa, California) said farmers would "likely" or "very likely" actually use free technical assistance. The "very likely" component ranged from 23 to 35 percent. The Wisconsin Rural Development Center asked about on-farm technical expertise as well as local demonstrations and educational workshops. For all three, a majority of respondents said these aids would "likely" or "very likely" increase the chance farmers would reduce chemical use.

In similar questioning, Padgitt (1987) posed the context of wholesale taxes on fertilizers and pesticides rather than federal funding to pay for research and education. He found levels of support similar to the Esseks study when proceeds were to be earmarked for agricultural research. Fewer, but still a majority, supported taxes to be used for educational programs. Less than half of the farmers supported taxes on pesticides if the revenue was earmarked for enforcement purposes.

Incentives and Disincentives

Research and educational programs that emphasize less chemical use are, essentially, an incentive policy. (Alternatively if existing educational programs promote greater rather than less use, this could be viewed as a disincentive for change.) More traditionally, however, incentives are identified in an economic context. Reactions to several kinds of incentives have been obtained in recent surveys. For example, in the Wisconsin Rural Development Center's study a majority of respondents said cost-sharing compensation for losses related to reducing chemicals would "likely" or "very likely" increase the chance they would reduce chemical usage. Similarly, a majority said if market premiums existed for commodities produced with less chemicals they would likely cut chemical use. Not as much support (about one-third indicating interest) was found for short-term loans to help cover costs of new equipment.

Some have suggested that current farm policy encourages greater use of chemicals (Duffy, 1987 and Fleming 1987). One issue is loss of base acreages for certain crops if rotational cropping is practiced. Esseks found that farmers consider this to be an important disincentive, especially in his Iowa and Wisconsin samples. In larger statewide samples, Padgitt obtained similar results in Iowa, but the Wisconsin Rural Development Center found less negative sentiment in Wisconsin than Esseks. Thus, concern over base acreage as a disincentive may be greater in the corn belt than elsewhere.

Iowa farmers were also asked about a policy whereby farmers could lower chemical application rather than idle a portion of their base acreage in order to qualify for federal program benefits. Although considerable interest was expressed, slightly more opposition (55 percent) than support (45 percent) was found.

Other unconventional (and perhaps nonfeasible) policies were posed in the Iowa survey in order to obtain a sense of whether farmers were open to and interested in new approaches. One proposal was a kind of "reverse-drought" insurance. It was based on an assumption that high nitrogen rates are cheap insurance if excessive rainfall causes leaching and reduced yields. The ratio of opposition to support was about two to one.

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Several surveys have asked about taxing as a disincentive. Farmers have expressed support for modest taxes, but strong and widespread opposition to taxing at levels high enough to discourage chemical use. Esseks (1988b) reported between five to 33 percent supported such an approach, depending on the state, and Padgitt (1988c) found 15 percent support.

Regulation

Regulation is rarely popular public policy, and perhaps this is especially the case for agriculture. Independence is strongly imbedded in the American creed and agrarian values. Work by Hoiberg and Bultena (1981), however, found farmers distinguished among combinations of regulatory practices and did not universally reject regulation. For example, they found different orientations toward regulation related to soil conservation/land use; agriculture safety/production; and feed additives/pesticides. Likewise, Gillespie and Buttel (1989) challenge earlier conclusions that opposition to regulation universally exists across all segments of the farm population.

There is some suggestion that farmers have moderated their opposition to chemical regulation over the past decade. Of the Iowa farmers Hoiberg and Bultena studied in 1977, 42 percent said there was too much governmental involvement in pesticides and their application. That is almost double what was found within the same population ten years later (Padgitt, 1988c). Although earlier baseline data were not available, recent studies in Virginia (Halstead et al., 1988a) and Minnesota (Downing et al., 1988) revealed levels of opposition to regulation similar to those of the recent Iowa study. More divided responses came, however, to questions about whether more regulation was needed.

The policy implications of such responses are difficult to gauge, partially because respondents have not always been provided clear referents. One factor that might lead to over estimated support for regulation is a feeling that regulations would affect "the other guy". Drudik (1988) reported that initial support for a nitrogen management project in Nebraska was based upon farmers' beliefs that their neighbors not themselves were mismanaging. Such a response bias reveals itself in answers to Esseks' question about required training, testing and licensing of applicators of chemicals -- something that would personally affect the respondent. Modest but not majority support was found for increasing these standards.

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Esseks gave situational information in questioning about regulation. For example, he asked about bans on fertilizers and chemicals near wells in areas or watersheds that might be especially threatened. There was majority support in three of five states (Florida, 69 percent; Iowa, 67 percent; and Wisconsin, 56 percent); less than majority in two (California, 47 percent; and Pennsylvania, 39 percent). Restricting the timing and amounts of manure that could be applied in such a area, however, did not receive majority support in any of the five samples. A majority of respondents in four of the five samples (the exception being Pennsylvania) supported restrictions on pesticide applications on vulnerable land.

Variation in policy preferences in relation to independent variables

In a forthcoming publication, Gillespie and Buttel (1989) explore the issue of farm operator opposition to government regulation of agricultural chemicals. Their analysis and empirical research challenges the widely held position that farmers are almost universally opposed to government regulation of agricultural chemicals, and lead them to conclude that such opposition is, in substantial measure, ideological rather than based on material interests in the use of particular chemicals or pharmaceuticals.

Gillespie and Buttel also explored the relationships between opposition to government regulation and selected social class and farm operation characteristics of respondents. They found, as have others, that opposition to regulation tended to come from larger farms, but was unrelated or only weakly related to such personal characteristics as age and education.

Gillespie and Buttel stress farmer ideology as the root base for farmer's opposition to regulation. A number of factors, such as sociopolitical attitudes and denial of product side effects, were identified as contributing to this ideology, and the former may have contributed to the weak relationship found between agrarian social class (including income variables) and opposition to regulation.

Implications for policy

Although the findings in this section largely document reactions to hypothetical policy proposals, responses give some indication of how farmers might view similar legislative proposals. Not surprisingly, widespread support was found for options that would increase farmers' repertoire of alternatives. This is a policy farmers are familiar with and like.

Their survey responses go beyond interest, and indicate a willingness to actively evaluate new technologies for their own farms. Farmers are interested in removal of disincentives they believe to exist. Voluntary approaches have greater appeal than regulation.

Two critical questions remain: to what extent can voluntary approaches prompt change; and what kinds of regulation would be acceptable policy? The studies provide some, although not a strong, basis for speculation. Whether voluntary efforts would be sufficient to alleviate a problem would depend upon the extent of change needed and the extent alternatives do not disrupt farming profitability and established practices. For example, if only modest reductions in nitrogen rates would be sufficient to bring nitrates in groundwater to acceptable levels, there may be a high potential for this to occur with a voluntary approach. On the other hand, if major reductions are necessary, policies may need to move along Esseks' continuum toward controlling behavior. But if major changes are needed, communicated to, and understood by farmers, control policies may be quite acceptable, provided they are perceived as fairly implemented.

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SUMMARY

The locality-specific nature of past surveys involving farmers' attitudes toward agricultural chemicals and groundwater quality makes it difficult to offer a national perspective. Although the contribution of a nationally based study of the farm population would be desirable, this would be a major undertaking. The study would need to consider major geological and agricultural systems variations that were not as problematic in the state and substate survey regions.

In spite of limitations of the existing literature, a number of recurrent messages are evident. Farmers are aware of the groundwater issue and recognize, at least minimally, their own farming systems' contribution to the problem. Farmers expressed a strong desire for measures to avoid further degradation of water resources. Farmers also expressed concern about impacts on health. This makes public intervention acceptable if not desirable for many. Farmers expect government to protect and if necessary intervene in order to protect groundwater resources.

The findings about how farmers perceive risks on their own farms are somewhat ambiguous. Considerable "concern" and "worry" exist, but extensive direction for action is absent. The lack of action may be a result of their perceived lack of viable options. Although the experience of low-input agriculture adherents is mostly to the contrary, the general population of farmers thought that reducing chemical inputs would result in lower yields and lower profits. They also saw disincentives for rotational options in existing farm programs.

Farmers appear to be less hostile to governmental intervention in the area of pesticide regulation than they were a decade ago.

Farmers expressed more support for policies that would increase their repertoire of options than for disincentives or regulatory options. Taxation of agriculture if used to support research and education received support. Farmers also indicated interest in products of research. Farmers were opposed, however, to taxing farm chemicals at levels designed to discourage chemical use.

Except for larger row-crop farmers who tended to be more opposed to policies limiting the use of chemicals, many of the attitudes cut across age and educational groups. Age and education are not strong predictors of agricultural chemical and groundwater attitudes. Only a few studies have reported gender differences as a variable. A recent hypothesis has been offered that opposition to regulation of agricultural chemicals may be as strongly related to farmer ideology, or a farmer subcultural belief system, as it is to actual use or dependence upon chemicals in farming operations.

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Footnotes

[1] In any discussion of agricultural chemicals and groundwater quality, at least two classes of chemicals need to be distinguished: fertilizers and pesticides. All three major plant nutrients, nitrogen, phosphorous, and potash, contribute to nutrient over-load and subsequent ecological imbalances in surface water. In groundwater, however, the environmental concern is primarily limited to nitrate-nitrogen. Nitrate-nitrogen is highly water soluble and is mobile in the soil. High levels of nitrate-nitrogen in the drinking water are linked with the sometimes fatal health condition, methemoglobinemia. Although findings are generally regarded as inconclusive, some studies have suggested prolonged ingestion of drinking water with elevated rates of nitrogen may also be associated with certain cancers.

Although the distinction between fertilizers and pesticides is critical, to aggregate all synthetic agricultural pesticides into one category is overly simplistic. It does not take into account variation in products and what the differential impacts of individual compounds may be on groundwater quality. There are at least four major classes of agricultural pesticides: herbicides, insecticides, nematocides and fungicides. Of these, herbicides constitute the greatest introduction of synthetic compounds into the environment in terms of total pounds of active ingredients. Herbicides account for 82 percent of pesticides used in production of major field and forage crops (U.S. Department of Agriculture, 1983). Because herbicide products vary in terms of their toxicity, solubility, and persistence, the risk various products pose to the environment varies.

[2] This study was conducted prior to legislative debate about the state's groundwater protection act, but at a time when the presence of agricultural chemicals in groundwater was receiving considerable media attention. However, there was publicity at the same time about industrial chemical residues the in public drinking water of the state's largest city.

[3] Statements and percent agreeing were: I have already reduced my chemicals as much as I can, 74%; my farm is too large for me to reduce my chemicals without adding more labor, 44%; I would need to purchase new equipment, 46%; I would be misunderstood or criticized by neighbors, 14%; I would lack access to reliable information on alternative management techniques for this farm, 28%; I'm not sure how to apply alternative practices to this farm, 52%; I would have to reduce my base acreage for government programs, 13%; Doing so would be less profitable than my present system, 68%; I would have more difficulty obtaining operating credit, 24%; insect and weed pests are too severe on my farm to depend on alternatives to chemicals, 46%.

[4] The nine most prevalent concerns were: whether the product might be harmful to my health or my family's health; whether the product might affect groundwater quality; whether the product is good for the soil; whether I have had success with the product before; whether the product might be harmful to birds or other wildlife on my farm; whether the product might affect my livestock's health in a negative way; whether the product makes my crops healthier; cost of the product; and whether the agricultural extension agent recommends the product.

[5] Various terms are used, sometimes synonymously, but more often ambiguously. This includes alternative agriculture, organic farming, and regenerative agriculture. Buttel et al. (1986) preferred the term "reduced-input agricultural systems." U.S.D.A. uses the acronym LISA (Low input sustainable agriculture).

[6] Studies from nine states are used in the analysis. Urban IPM and the Kentucky stored grain surveys were purposely omitted. The Washington alfalfa study was unavailable to the author.

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TABLES

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Table 1. States from which farmer survey findings are quoted.

State	Reference	Geographical base	Topic areas
California	Esseks, 1988a, 1988b	Single county	Attitudes, policy
Florida	Esseks, 1988a, 1988b	Single county	Attitudes, policy
Georgia	Rajotte et al., 1987	Statewide	Farm practices
Indiana	Rajotte et al., 1987	Statewide	Farm practices
Iowa	Esseks, 1988a, 1988b;	Single county	Attitudes, policy
	Lasley, 1983, 1984, 1988;	Statewide	Attitudes, policy, farm practices
	Padgitt, 1987, 1988a, 1988b, 1988c	Statewide/County	Attitudes, policy, farm practices
	Halstead et al., 1988	Comparative county	Attitudes, policy, farm practices
Massachusetts	Rajotte et al., 1987	Statewide	
Minnesota	Downing, 1988	Regional	
Mississippi	Rajotte et al., 1987	Statewide	
New York	Buttel and Gillespie, 1988	Statewide	Policy, farm practices
	Gillespie and Buttel, 1989	Statewide	Policy, farm practices
	Rajotte et al., 1987	Statewide	Farm practices
North Carolina	Anderson, 1988	Statewide	Attitudes, practice adoption
	Rajotte et al., 1987	Statewide	Farm practices
Oklahoma	Moore, 1988	Not defined	Attitudes, policy
Pennsylvania	Esseks, 1988a, 1988b	Single county	Attitudes, policy
Virginia	Rajotte, 1987	Statewide	Farm practices
	Halstead et al., 1988a	Single county	Attitudes, farm practices
	Halstead et al., 1988b	Comparative county	Attitudes, policy, farm practices
Wisconsin	Esseks, 1988a, 1988b	Single county	Attitudes, policy
	Wisconsin Rural Development Center, 1989	Statewide	Attitudes, policy, farm practices

Table 2. Ranking of issues and position of drinking water as an issue.

Study	Sample/ Sample Segment	Rank/total issues ranked	% assigning highest rating to water quality
Padgitt (1987)	Farm operators	2.5 of 6	67**
	Farm operators	2 of 6	67**
	Rural non-farm	1 of 6	78**
	Rural non-farm	1.5 of 6	76**
Padgitt (1988[a])	Farm operators	3 of 6	64**
Padgitt (1988[b])	Farm operators	2 of 7	57**
Halstead et al. (1988)	Farm operators	1 of 6	76**
Lasley (1988)	Farm operators	3 & 9 of 19	56/45***
Downing et al. (1988)	General household	1 of 6	84*
Iowa DNR (1986)	General household	3 of 6	24****
	Farm subset	1 of 6	30****
Center for Comm Dynamics	Adult U.S. population	5 of 8	55*

* 4-point scale

** 5-point scale

*** 7-point scale

**** Selection of top issue only

Table 3. Iowans' perceptions of groundwater pollution sources.

Source*	Percent responding "A Great Deal" All respondents N = 400	 Farm households N = 78
Farm pesticides	67	52
Farm fertilizers	58	35
Hazardous waste disposal	39	30
Landfills and abandoned dumps	34	35
Accidental spills of hazardous materials	28	20
Leaking underground storage tanks	28	19
Use of pesticides and fertilizers inside of cities and towns	21	6
Application of animal manure, sewage and industrial waste on land	21	12
Agricultural drainage wells, sinkholes and abandoned wells	20	15
Septic tanks	8	2

* Items were asked in random order during interviewing.

Source: Iowa Department of Natural Resources, 1986.

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Table 4. Summary of studies inventorying concern about agricultural chemicals (fertilizers and pesticides) posing a health threat.

Location/Response	Big Spring		Northeast Iowa		Southwest Minnesota			VA Dairy	Southwest	Northwest
	Farm[a]	Non-farm[a]	[a]	Non-farm[a]	Rural Non-farm[b]	Town[b]	Farm[b]	Farmer[c]	Iowa[d]	Iowa[e]
	Percent responding									
In the nation										
Very concerned	52	74	63	67	64	89	80	46	50	45
Somewhat concerned	42	25	46	29				47	39	44
Not at all concerned	2	0	0	0				1	3	4
Not sure	5	1	1	4				7	8	2
In your state										
Very concerned	64	81	63	82	73	89	86	52	64	58
Somewhat concerned	32	18	37	18				43	28	37
Not at all concerned	0	1	0	0				1	3	2
Not sure	2	0	0	0				4	5	2
In your county (region)										
Very concerned	72	84	59	71	73	92	85	57	65	63
Somewhat concerned	25	15	39	17				39	28	33
Not at all concerned	0	0	1	0				1	2	2
Not sure	2	1	1	12				3	5	2
On your own farm										
Very concerned	71	X	57	X	X	X	X	56	63	69
Somewhat concerned	25	X	31	X				36	25	26
Not at all concerned	2	X	9	X				3	7	2
Not sure	2	X	1	X				5	5	2

X = Not asked.

[a] From Padgitt, 1987

[b] From Downing et al., 1988

[c] From Halstead et al., 1988

[d] From Padgitt, 1988a

[e] From Padgitt, 1988c

Table 5. Selected findings from a national study on adoption of Integrated Pest Management (IPM).

Crop/Location	Level of IPM Use Non-users	Low-level Users	IPM User (Level not separated)	High-level Users
Corn/Indiana				
Number of respondents	123	108		166
Average yield (bu/acre)	104.4	112.5		115.0
Pesticide applications (#/yr)				
Herbicide	1.01	1.20		1.29
Insecticide	0.16	0.33		0.39
Total pesticide costs ($/acre)	17.41	23.46		25.30
Cotton/Texas				
Number of respondents	139		633	
Average yield (#/acre)	430.4		588.7	
Pesticide costs ($/acre)				
Herbicide	10.35		9.28	
Insecticide	14.60		26.20	
Cotton/Mississippi				
Number of respondents		39		261
Average yield (dryland) (#/acre)		629.6		749.9
Pesticide costs ($/acre)				
Herbicide		20.74		30.90
Insecticide		39.91		47.83
Peanuts/Georgia				
Number of respondents	78	74		224
Average yield (#/acre)	3155.5	3285.8		3504.1
Pesticide applications (#/yr)				
Herbicide	2.01	2.04		2.30
Insecticide	1.67	2.07		1.70
Fungicide	4.28	5.19		4.82
Total pesticide costs ($/acre)	48.93	38.11		43.79
Tobacco/North Carolina				
Number of respondents	47	77		222
Average yield (#/acre)	2265.0	2265.0		2277.7
Pesticide applications (#/yr)	3.7	3.2		3.1
Pesticide costs ($/acre)	56.58	53.97		56.71
Apples/New York				
Number of respondents	42	160		16
Average yield (bu/acre)	449	518		545
Average price ($/fresh bushel)	3.68	3.83		3.80
Pesticide applications (#/yr)	11.5	11.3		13.2
Pesticide costs ($/acre)	169.25	156.17		143.64
Apples/Massachusetts				
Number of respondents	43		45	
Average yield (bu/acre)	344.5		386.5	
Average price ($/fresh bushel)	8.00		7.43	
Pesticide applications (#/yr)				
Herbicide	1.2		1.0	
Insecticide	9.6		8.2	
Fungicide	11.4		12.4	
Miticide	2.1		1.8	
Pesticide costs ($/acre)	226.93		161.85	
Almond/California				
Number of respondents	82	39		117
Percent of total production rejected (1984)	2.5	1.2		1.9
Pesticide management (% "Sometimes" + "Always")				
Dormant spray	82.7	97.4		98.3
May sprays	65.3	88.6		84.4
July sprays	67.6	94.6		87.4
On-farm fumigation	15.7	24.3		36.2
Herbicide as only weed control	40.5	46.2		59.7
Virginia/Soybeans				
Number of respondents	67	67		133
Average yield (bu/acre)	27.4	26.6		29.9
Pesticide applications (#/yr)				
Herbicide	0.97	0.88		1.21
Insecticide	0.15	0.11		0.27
Pesticide costs ($/acre)	15.15	15.92		18.64

Source: Virginia Cooperative Extension Service. The National Evaluation of Extension's Integrated Pest Management (IPM) Programs (1987). Adapted from appendices 2, 3, 4, 5, 6, 7, 8, 9, 11.

Table 6. Perceived selling points for Integrated Pest Management: Comparison of non-users and high level users.

	Level of IPM use*															
Selling point	Virginia Soybean Growers		Indiana Corn Growers		Georgia Peanut Growers		North Carolina Tobacco Growers		Massachusetts Apple Growers		New York Apple Growers		Texas Cotton Growers		Mississippi Cotton Growers	
	Non User	High User	Non User	High User	Non User	High User	Non User	High User	Non User	User	Non User	High User	Non User	User	Non User	High User
Increased farm profits	100	97	86	89	88	94	94	94	76	95	92	85	77	90	94	97
Increased crop yield and quality	94	94	83	91	93	98	83	94	67	95	92	92	81	91	92	96
Reduces personal health hazard	80	93	90	82	73	82	83	89	NR	NR	NR	NR	NR	NR	NR	NR
Reduces family health hazard	NR	NR	84	84	NR	NR	83	88	NR	NR	NR	NR	NR	NR	NR	NR
Safe use of pesticides	100	94	84	82	70	87	94	90	87	98	92	85	77	82	76	86
Protects public health	80	92	82	80	NR	NR	94	84	NR	NR	NR	NR	NR	NR	NR	NR
Increases knowledge of pest and control options	90	90	83	79	88	93	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Promotes less toxic and small quantities of pesticides	90	90	78	76	NR	NR	88	92	NR	NR	NR	NR	61	77	72	88
Reduces environmental damage	44	91	75	75	77	91	88	92	92	100	88	92	63	73	80	82
Increases peace of mind	80	85	76	74	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Better way of pest control	89	94	68	72	94	95	77	94	NR	NR	NR	NR	76	87	92	94

*On a rating scale of 1 to 4, with 1 being not important and 4 being very important, values represent sum of respondents answering either 3 or 4.

NR = Not reported

Source: Rajotte et al., 1987.

Table 7. Profile of New Farm subscribers.

Characteristic	Full-time N* = 294	Part-time N* = 199	Total** N*= 661
Average value of total assets (farm and home)	$408,150	$228,280	$301,210
Total farm sales in 1987	$119,810	$23,700	$67,350
Cash grain major enterprise	38%	24%	30%
Graduation from 4-year college	36	26	34
Chemical weed control - current			
Non-chemicals	10	28	23
In emergencies	13	24	18
Moderate use	70	46	54
Intensive use	7	2	5
In past five years, quit/reduced:			
Using herbicides	NR	NR	33
Using insecticides			26
Impact on income of quit/reduced using chemicals (N = 312)			
Increased income			27
No change			66
Decreased income			7

***N = Number of respondents**

****All respondents in the study were farm operators; however, a portion identified occupations or statuses other than farmer. Hence, full-time and part-time do not sum to total respondents.**

Source: Data Probe, Inc. (1988) (Permission to quote granted to author from Rodale Press, November, 1988).

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Table 8. **Reasons for having reduced or quit using chemicals.**

Reason	Total Sample % of 312	Mostly Dairy % of 45	Mostly Hogs % of 39	Mostly Beef % of 46	Mostly Cash grain % of 99
Environmental concern	68	78	68	59	64
Personal/family health safety	67	75	60	64	56
Cut production costs	63	70	71	43	81
Reduce liability risk	11	18	5	16	9
Increasing government regulations	5	5	2	2	7
Receive market premiums	5	2	0	2	4

Source: Data Probe, Inc., 1988. Permission to quite granted to author from Rodale Press, November, 1988.

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Table 9. **Degree of preference among random sample of New York farmers for low input alternative for eight crop production practices.**

Phase of Crop Production	Percent N = 309
Seed varieties with moderate yield, high pest resistance	86
On-farm fertility sources	66
Cultured practices for weed control	45
Natural controls for insects	44
Natural control for diseases	74
As few tillage operations as necessary	49
Several crops, regular rotation	40
More labor, less purchased products	36

Source: Buttel and Gillespie (1988).
Note: For each of the eight phases, respondents were presented with paired descriptive alternatives. Answers were to be based on preference under the assumption that both practices described would yield about the same net profit.

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APPENDIX

Annotation of Selected Empirical Studies

This appendix presents a brief summary of several studies cited in the main text.

The annotation of findings was not necessarily designed to be a summary of the entire study. Rather entries are limited to those findings bearing the most directly on issues/policies/practices relevant to agricultural chemicals and groundwater quality.

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
Anderson (1988)	Adoption of practices substituting for high chemical inputs	1988	North Carolina farmers a) "alternative" production sample (N=267) b) "conventional" sample (N=303)	a) Alternative farmers compared with conventional farmers had significantly less acreage in cultivation, lower rented-to-owned land ratios, lower farm incomes, and slightly higher educational levels. b) For both groups reasons for deciding to use particular chemicals were personal health, environmental consequences and previous success. c) Importance assigned to environmental consequences of chemicals distinguished among alternative, part-time, and full-time conventional farmers. Alternative farmers were most concerned about non-human effects. d) Cost of chemical products was more a concern of full-time conventional farmers than it was of part-time conventional farmers.	Mail questionnaire. Response rate for "alternative sample was 79%; response rate for "conventional" sample was 53%. Samples were pooled and three clusters of farmers distinguished. Sub-grouping should be basis for any generalizations.
Buttel & Gillespie (1988)	Issue attitudes/ Adoption motivation	1987	a) Conventional farm operators, state of New York (N=317) b) Members of Natural Organic Farmers Assoc. New York (NOFA-NY) (N=71)	a) Conventional farmers gave divided opinions on statements related to agricultural chemicals and environment: 1) The pollution effects of nitrate fertilizers are quite unimportant compared to all their benefits" (45% disagree, 32% neutral, 23% agree). 2) "There is too much talk about all the harmful effects of pesticides and not enough about their benefits" (38% disagree, 22% neutral, 40% agree). 3) "Environmentalists have greatly exaggerated the dangers of nitrate fertilizer pollution" (28% disagree, 42% neutral, 30% agree). b) Nearly universal disagreement to the above three items (96%) existed among NOFA-NY respondents. c) Within the conventional sample smaller farmers expressed greater environmental concern. d) On eight forced-choice items, conventional farmers more often chose the low input alternative for eight separate phases of crop production.	Separate random samples were developed. Mailed questionnaire was used to collect data. Conventional sample generalizable to New York farm operator population. Organic sample restricted to farmers with membership in New York State chapter of the Natural Organic Farmers Association.

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				e) Among conventional farmers, small farmers more often chose the low input alternatives for weed control, tillage, crop mix, and purchased inputs. Commercial farmers tended to prefer less tillage. No differences were found for seed selection, fertility, insect control and disease control. f) Authors conclude "there may be great untapped potential for agricultural researchers and policy-makers to increase the ability of the vast rank-and-file of nonorganic farmers to employ resource conserving, more environmentally sound, reduced-input practices."	
Center for Communication Dynamics (1985)		1985	a) U.S. adult (N=401) b) Wisconsin adult population (N=200)	a) All identifiable social trends point to increased public concern and regulation interest in both surface and groundwater contamination. b) Water related issues received somewhat less concern than air pollution and nuclear wastes. c) Wisconsin sample much like national sample except for more Wisconsin respondents were more likely to view underground water pollution and sewage disposal into rivers as national problems (58% vs. 48% and 70% vs. 59% respectively). d) Attitudes were generally unrelated to social characteristic variables. Concerns were remarkably pervasive throughout the population.	Telephone interviews, random digit dialing. Sampling error at 95% confidence level: +/-7% for Wisconsin sample, +/-5% for national sample.
Data Probe, Inc. (1988)	Practice adoption, motivation for adoption	1988	Subscribers to New Farm magazine (N = 661)	a) Profiles of farmers do not conform to stereotapes of organic farmers in terms of education and size of farms. b) Among respondents reducing or quitting use of chemicals, three major and fairly equally distributed reasons were cited: environmental concern (68%), personal/family health and safety concerns (67%), and cut production costs (63%). c) Among most cash grain farmers, reasons for reducing chemicals were cutting production costs (81%), environmental concern (64%), and health and safety (56%).	Random sample of farm operators of subscriber population. Mail questionnaire. Sample likely to be homogeneous on sustainable agriculture values promoted in the publication. Generalization is to subscriber population.

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				d) Of the sample respondents, changes in farming operations in the past 5-years included: quit/reduced herbicides, 33%; quit/reduced use of fertilizers, 26%; quit/reduced insecticides, 26%; increased herbicides, 4%; increased fertilizers, 13%; increased insecticides, 3%.	
Downing, et al. (1987)	Attitudes toward issue/policy preferences	1986	Households in 19 county area of Southwestern Minnesota (N=630)	a) Protecting water quality rated higher than five other issues. b) Farmers, in comparison to their non-farm and town counterparts, were more likely to agree: 1) "that agricultural chemicals if used as directed are not a threat to the environment" (48% vs. 15% vs. 22%); 2) "there is too much regulation on pesticide use" (20% vs. 7% vs. 8%); 3) "current programs and regulations are inadequate to protect groundwater" (37% vs. 14% vs. 15%); 4) "petroleum spillage accounts for more contamination than agricultural chemicals" (30% vs. 15% vs. 16%); 5) "groundwater contamination is more of a concern in urban areas than in rural" (29% vs. 15% vs. 20%). c) Farmers, in comparison to their non-farm and town counterparts, were less likely to agree: 1) "current production levels could be maintained with less use of fertilizer" (53% vs. 67% vs. 64%) 2) "protecting the environment is so important that requirements cannot be too high" (63% vs. 93% vs. 82%). d) Although most respondents were "very worried" that agricultural chemicals pose a health risk to people locally, farmers were less worried than their rural non-farm and town counterparts (73% vs. 90% vs. 85%)	Simple random sample from commercial mail list developed from telephone directories. Mailed questionnaires to a sample of 3,000 resulting in 21% response rate. No second follow-up mailing used. Original sample generalizable to population. No analysis provided to assess bias of non-respondents. Care should be exercised in generalizing to population of region due to low response rate.

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				e) State government was a clear preference over federal or local/county government to enforce existing (or future) water quality policies.	
Esseks, (1988a, 1988b)	Attitudes toward issue/ Policy preferences	1988	Five parallel studies Random samples of farm operators Lancaster Co., PA (N=135) Jackson Co., FL (N=157) Portage Co., WI (N=160) Cherokee Co., IA (N=154) Stanislaus Co., CA (N=117)	a) Perception that problem ag chemicals in groundwater was nearly universal (90+ percent in all studies). b) Those who said they were worried about agricultural chemicals, fertilizer or manure being in their drinking water ranged from 45 percent in Stanislaus County, CA to 64 percent in Jackson County, Florida. c) Strong support (70+ percent) found for policies supporting research and education to reduce dependence on ag chemicals. Less support for anticipated use of technical assistance. d) Majority in each study said that profits would be reduced for themselves if fewer chemicals used. e) From two-fifths to three-fifths believe they have already found economic ways to reduce chemicals. f) Farmers quite divided about regulation policy issues. In all five states more opposition found for restricting manure applications than for restricting pesticides and fertilizers, or banning ag chemicals near wells.	Telephone interviews, Response rate ranged from 68 percent to 83 percent. Single studies generalizable to multi-township sites within the respective counties. Aggregation among states
Freshwater Foundation (1987)	Policy preferences	1987	Self selected attendees at national conference: 27% agency employees, 21% university, 8% farmers, other categories 7% or less (N = 212)	a) Three of five attendees felt the economics of staying in business was the driving forces behind agrichemical use. This reason was chosen much more frequently than advertising (11%), tradition (11%), government policies (8%), or market pricing (3). b) Three factors felt to be major constraints to effective management of agrichemicals and protection of groundwater were: 1) lack of incentives to change current practices, 2) inadequate information, and 3) potential loss of income. c) Responsibility for protecting groundwater from agrichemical contamination was assigned most frequently (30%) to a partnership among government agencies, farmers, farmer organizations, the chemical industry, and society as a whole	Self administered questionnaires filled out and returned during three day conference. Two-thirds of attendees completed form. Generalization not justified beyond the sample itself.

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				Nineteen percent thought responsibility should be with farmers/users/growers, 10% assigned responsibility to federal agencies, 10% assigned it to a partnership of users producers, and 8% identified the agriculture industry.	
Gillespie and Buttel	Policy preferences, correlates of regulation opposition	1982	New York farm operators (N=456)	a) Social class, willingness to assume risk, and importance placed on profit making were directly related to opposition to government regulation.	Mail questionnaire. Response ratio was 69% Generalizable to active farm operators in New York
				b) Farm men's off-farm work, cynicism toward agribusiness, non-economic orientation towards agriculture, perceptions of potential side side-effects of agricultural chemicals and drugs, and liberal political attitudes were inversely related to opposition to regulation.	
				c) Conclusion is drawn that opposition to government regulation of agricultural chemicals is primarily due to farmer ideology and has little to do with whether farmers actually use the chemicals.	
Halstead et al. (1988a)	Attitude toward issue/ practice adoption	1987	Grade A Dairy operations in Rockingham County, VA (N=147)	a) Two of five farmers follow fertilizer recommendations without regard to manure applications. Thirty percent did not know nutrient value of manure.	Mailed questionnaire with follow-up. Full sample was complete enumeration of population. Response rate was 50%. Study generalizable to dairy farmers in Rockingham Co.
				b) Of six public issues, three received nearly equal rating (protecting water quality, preventing soil erosion, attaining profitability in agriculture).	
				c) Respondents consistently disagreed with position that degradation of groundwater and environment was acceptable trade-off for improved profitability.	
Hoiberg and Bultena (1981)	Policy preferences	1977	Iowa farm operators (N=940)	a) Farmers were generally split on whether governmental involvement in pesticides and their application was too much (40%) or about right amount (41%). Few (13%) felt there was too little involvement.	Area probability sample. Statistical generalization is to Iowa farm operators with 1976 gross sales of $2,500 or more.
				b) Tendency to answer "too much involvement" was more prevalent among older respondents, respondents with larger farms, and farmers having less trust in government. Educational attainment and political efficacy were unrelated to positions on pesticides.	

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
Iowa Department of Natural Resources (1986) (Also Padgitt and Hoyer, 1987)	Policy preferences	1986	Adult Iowans (N=400)	a) Eighty-three percent of respondents want more done to solve groundwater pollution problems in the state, 10 percent said enough is already being done.	Telephone interview with statistical probability of households in the state.
				b) Eighty-four percent either favored or strongly favored more stringent regulations on use of pesticides, 77 percent favored tighter restrictions on fertilizers. Among farmers (N=78) 65 percent favored tighter restrictions on pesticides and 52 percent backed more controls on fertilizers.	
				c) Fifty-seven percent of all respondents said taxes should be imposed to discourage excessive pesticide and fertilizer use; 39% were opposed. Among farmers, 43% favored and 50% opposed such a taxing policy. (Remainder were undecided.)	
Kaap (1986) (also Padgitt, 1987)	Attitudes/practice adoption	1984, 1986	Big Spring Basin (N=207 and 229)	a) Availability of nitrogen greatly exceeded crop needs.	Personal interviews. Response rate 90+ percent. Sample is population for for basin. No generalization beyond basin.
				b) Farmers not adequately crediting manure and rotating crops.	
				c) Forty percent of farmers reduced nitrogen rates between 1984-86.	
				d) Concern about issue high. Majority of farmers willing to support tax increases if revenue used for research and education.	
				e) Farmers opposed relaxing standards to stimulate economic growth.	
Lasley (1988)	Issue attitudes	1988	Active Iowa farm operators (N=2000)	a) Water quality and agricultural chemical issues rated high on policy agenda. Nineteen rural issues rated. "Presence of pesticides, herbicides and other chemicals in drinking water" rated third behind prices for farm products and federal budget deficit. Over half (56%) used highest category on 7-point scale in rating pesticide item.	Random sample. Mail survey by state agricultural statistical reporting service. Response rate approximately 60 percent. Findings generalizable to Iowa farm operators.
				b) Other issue-related items and percent using highest category in answering included: adverse health effects from exposure to agricultural chemicals, 48%; residues such as pesticides and herbicides in food products, 46%; contamination of underground water supplies, 45%; use of food additives and preservatives, 27%	

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization Limits
Lasley (1984)	Issue attitudes	1984	Active Iowa farm operators (N=2000)	a) Most respondents (80%) felt problems of drinking water quality on their own farm did not exist or were slight.	Random sample. Mail survey by state agricultural statistical reporting service. Findings generalizable to Iowa farm operators.
				b) Estimates of problems were progressively greater as estimates moved to one's town, the state and the nation.	
				c) Of five sources of water pollution in Iowa, pesticides and fertilizer run off and industrial wastes ranked higher than soil erosion sediment, municipal sewage, and animal waste. No difference in ratings existed between the top two sources.	
Moore (1988a)	Issues attitudes/ Policy	1987	Rural Oklahoma opinion leaders (N=56)	a) On 5-point scale 18 percent were "strongly concerned" about water quality, 48 percent "tended to be concerned," 32 percent was "uncertain"; and 2 percent tended to be unconcerned.	Sample (N=56) drawn from attendees at three conferences. Sample divided between full-time farmers (N=12), part-time farmers (N=18), and non-farmers (N=26). Generalizability limited to sample itself.
				b) Expression of general environmental concern was similar but slightly greater than for water quality.	
				c) Strong association existed (r = .86) between water quality and general environmental concerns.	
				d) Respondents with gross family incomes of $30,000 or less expressed greater concern for water quality than did respondents from higher income levels.	
				e) No differences were found about concern for water quality based on levels of educational attainment.	
Padgitt, 1988a	Attitudes toward issue/ practice adoption/ policy preferences	1987	Active farm operators in Audubon County, IA (N = 203)	a) Protecting water quality of high importance, essentially equal to profitability in agriculture and soil erosion. Protecting water quality more a priority than diversifying agriculture.	Stratified random sample. Personal interviews. Study generalizable to Audubon County, a western county of the state, with primarily corn and soybeans as row crops and swine as livestock enterprises
				b) Respondents equally concerned about health risk of agricultural chemicals on own farms as in the county and in the county and in the state. Less concern expressed for problems in the nation.	
				c) Pesticides chosen more often as posing a greater health risk than fertilizers (65% vs. 2%).	

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				d) Equal concern found for residue in drinking water and risks in handling agricultural chemicals. Much less perceived risk from exposure to food residues, air pollution, and bathing/swimming. e) Of four groundwater policy goals, non-degradation was rated feasible most often (69%). Others, in order of preference, were restoration to purity (46%), pre-set standard (42%), variable standards based on aquifer use (37%), and self regulation (32%) f) Respondents disagreed that too much regulation of industry exists (64%), or that standards should be relaxed (73%). g) Most farmers (80%) indicated an interest in management alternatives to current reliance on agricultural pesticides, but a majority (55%) also said chemicals are their best alternative to control crop weeds, pests and plant diseases. h) Commercial nitrogen and herbicide applications were nearly universal (95+%). Herbicide applications mostly complied with label instructions. i) Commercial fertilizer rates on corn were generally within the land grant colleges recommended levels, but other on-farm sources were not fully taken into account. j) Yield goals were often based on criteria such as highest historical yield (56%), or potential of seed germ plasm (25%). Scientific criterion of soil CSR value was used by 28%.	
Padgitt (1988c)	Attitude toward issue/ practice adoption/ policy preferences	1988	Active farm operators in Iowa (N=593)	a) Of seven priority issues, profitability in agriculture ranked first, quality of the state's drinking water second, and agricultural health and safety third. (Other issues on list were controlling soil erosion, educational system in the state, economic development, and maintaining and improving highway and road system. b) Groundwater pollution was seen as a less serious problem on respondents' own farms (53% somewhat or very serious) than in their county (78%), in the state (90%) and in the	Mailed questionnaire from commercially purchased sampling frame. Response rate 64%. Findings generalizable to Iowa farm operators.

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				c) Few differentiations were made among nitrogen fertilizer, insecticides and herbicides relative to the extent they threaten groundwater quality in the state.	
				d) A majority of respondents opposed the following policies: tighter restrictions on use of farm pesticides and fertilizers, taxes set at levels to discourage fertilizer and pesticide use, substituting chemicals rather than idling land as production reduction strategy, and restricting chemicals but developing insurance programs when weather interferes with performance.	
				e) Of seven factors suggested as detractors to protection and sound management of agricultural chemicals, the two most frequently identified were lack of market incentives to change and belief that existing problems are not very serious.	
				f) Farmers estimated corn yields would decline an average of 25% under a herbicide ban and assuming continuation of existing tillage practices. Under alternative tillage a majority (52%) estimated production costs would increase and yields would fall 20% below existing levels.	
Padgitt and Hoyer (1987)	Attitudes toward issue/ policy preferences	1986	Adult households, State of Iowa (N = 400)	a) Of six statewide issues, quality of drinking water ranked third, behind schools, and economic development. Quality of drinking water ranked higher than soil erosion, maintaining highway system, and recreational facilities. No difference was found in ranking between farm and non-farm households for quality of drinking water. Farmers ranked the importance of soil erosion higher than quality of drinking water.	Random digit dial of Iowa households. Telephone interviews. Subsample of farm households, N = 78. Generalizable to Iowa heads of household. Subsample of farm households subject to sampling error.
				b) Of 10 sources of groundwater pollution in Iowa, both farmer and non-farmer householders ranked farm pesticides first and farm fertilizers second. In the ratings, non-farm householders assigned greater seriousness to these sources than did farmer householders.	

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				c) Of five hypothetical policies, more support than opposition was found for each. Strongest support was for research on safe use of fertilizers and pesticides (94%). Substantial support was also found for tighter restrictions on 1) farm pesticides (84%), 2) urban use of fertilizer and pesticides (80%), 3) use of farm fertilizers (77%). Respondents were most divided on taxing fertilizers at levels to discourage usage (57% support). Among farmer households more opposition than support was found. For all five policies, farmer householders were significantly more opposed/less supportive.	
Pins (1986)	Attitudes toward issue/ Policy preferences	1986	Adult households in Iowa (N = 801)	a) Fifty-two percent of the adult population identified farm chemicals as biggest threat to water they drink; 38 percent identified industrial waste. b) Three out of four Iowa adults believe their drinking water is safe for now, but 82% are concerned about pollution of their water. c) Three-fourths of respondents said use of farm and industrial chemicals must be reduced now because harmful effects will show up later when it will be too late. d) One in five support maintaining the status quo until harmful effects are better understood. e) Greatest concern for issue found among residents of small towns.	Telephone interview with Iowans 18 years and older. Random household selection. Findings generalizable to Iowa adults.
Rajotte et al. (1987, appendix 2)	Practice Adoption	1985(?)	Farmers producing almonds in California (N=238)	a) IPM users had more education, were more likely to be full-time farmers. b) IPM users in 1984 had less of their total production rejected. Less difference between users and non-users was found in 1982 and 1983. c) IPM users reported more spraying and fumigation. Also more apt to use herbicides as only means of weed control.	Random sample of producers for state census records. Study generalizable to producers of commodity in the state.

Study	Topic Area	Time	Sample Size (N)	Major Findings	Generalization Limits
Rajotte et al. (1987, appendix 3)	Practice Adoption	1985(?)	Extension agents mailing list to growers in Massachusetts (N=88)	a) IPM users had higher yields and received slightly less price for fresh produce. b) Little difference between users and non-users in number of pesticide applications per year (herbicides, insecticides, fungicide and miticide) but users had significantly lower total pesticide costs. c) Users and non-users similar in education and acres of apples grown. Users were younger.	Random sample from Extension agent's mailing lists to apple growers. Telephone interviews. Generalizability limited to representativeness of sampling frame which is undetermined.
Rajotte et al. (1987, appendix 4)	Practice Adoption	1984-85	Apple population growers in New York (N=218)	a) IPM users reported higher yields. b) IPM users reported lower pesticide costs. c) Users were younger, apples more dominant income source. d) Users more often identified use of natural enemies for pest control as selling point of IPM. Non-users more often identified increased farm profits as selling point.	Random sample from state crop reporting service. Telephone interviews from 4 regions. Findings generalizable to New York apple growers.
Rajotte et al. (1987, appendix 5)	Practice Adoption	1985	Indiana corn growers (N=397)	a) High IPM users were younger and had completed more formal education than had low users. Low users tended to be younger and had completed more formal education than non-users. High users farmed the most land and had the most acres of corn, followed by low users and lastly, non-users. b) No difference was found among the three use levels in percentage of total acreage treated (97-98%). Non-users were less likely to treat for insects (23%) than were low users (37%) or high users (41%). High IPM users incurred the greatest pesticide cost per acre ($25.30) followed by low users ($23.46 and non-users of IPM ($17.41). c) High users reported the highest per acre yield (115) followed by low users (112) and non-users (104). d) Respondents gave multiple "selling points" for IPM. Profits, yields, and health were the most frequently mentioned. e) "Selling points" of IPM generally cut across use levels. A slight tendency was found for users to identify economic advantages, and non-users to identify health reasons.	Random sampling, from state crop reporting service list, telephone interviewing. Findings generalizable to Indiana corn growers.

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
Rajotte et al. (1987, appendix 7)	Practice Adoption	1985	Cotton producers in 8 Texas counties (N=772)	a) IPM users reported higher yields. b) Herbicide costs of users was somewhat less than non-users ($9.28 vs. $10.35) but users insecticide costs were substantially higher ($26.20 vs. $14.60). c) IPM users tended to have more education and operate larger farming units.	Proportionate random sample from ASCS lists. Telephone interviews generalizable to areas in study.
Rajotte et al. (1987, appendix 7)	Practice Adoption	1986	Mississippi cotton growers (N=300)	a) High-level IPM users reported higher yields than low-level. b) High-level IPM users reported higher herbicide and insecticide costs. c) High-level IPM users tended to be younger, more educated and to operate larger units. d) Both high- and low-level users highly rated selling points of IPM.	Random sample from state census lists, telephone interviews, generalizable to state's cotton growers.
Rajotte et al. (1987, appendix 8)	Practice Adoption	1985	Farmers growing peanuts in Georgia (N = 376)	a) Level of IPM adoption was related to higher education, younger age, more acres farmed and owned (but not necessarily number of acres of peanuts grown), and higher gross value of farm products. b) Positive relationship between peanut yield and extent of IPM use. c) IPM users (in contrast to non-users) reported lower per acre insecticide costs, equal to herbicide costs, greater nematode and lower fungicide costs. d) Multiple reasons given to participating in IPM. Crop quality, better pest control and increased profits mentioned slightly more often than environmental and safety reasons.	Random sample from Department of Agriculture, telephone interviews. Study generalizable to peanut growers in Georgia.
Rajotte et al. (1987, appendix 9)	Practice Adoption	1985	Virginia soybean growers (N = 267)	a) IPM users were younger and had completed more formal education and operated larger farming units. A direct relationship was found between average gross value of all farm products sold and level of IPM use.	Telephone interviews with random sample. Findings generalizable to Virginia soybean growers, within margin of error of sample

Study	Topic Area	Time	Population/ Sample Size (N)	Major Findings	Methods/External validity/ Generalization limits
				b) High IPM users had the highest total pesticide cost, and made the most pesticide applications per year, but also had the highest yield, and reported higher prices received for their crop. c) Reducing environmental damage was cited as a "selling point" of IPM more frequently among high users (91%) and low users (84%) than non-users (44%).	size.
Rajotte et al. (1987, appendix 11)	Practice Adoption	1985(?)	North Carolina tobacco growers (N=346)	a) Little difference between non-users, low-level users and and high-level users in yields and costs. b) IPM users made fewer pesticide applications per year. c) High users were older, had less formal education.	Geographically statified random sample of Extension Service census records, telephone interviewing, generalizable to state's tobacco growers.
Wisconsin Center for Rural Development	Inventory of pest control practices, sources of nitrogen perceived barriers to to reduced chemical use	1988	Wisconsin farm operators (excluding vegetable and fruit farmers (N=389)	a) Most important reason farmers do not further reduce chemicals is belief they have already reduced as much as possible; less profitability was second most cited reason. b) Majority of farmers believe their current use of chemicals does not seriously or permanently harm the environment. c) Farmers generally lack accurate information regarding the extent of environmental/health risks form their practices. d) Farm chemicals in local groundwater would motivate many farmers to consider reducing chemicals on their farms. e) Availability of individual assistance by experts in an important factor in considering reduced chemical use.	Mail questionnaire; 52% response rate. Findings generalizable to Wisconsin farm operators excluding exclusively vegetable/ fruit farmers.

FARMER ADOPTION OF SOIL CONSERVATION PRACTICES: LESSONS FOR GROUNDWATER PROTECTION

by

Ted L. Napier
Department of Agricultural Economics and Rural Sociology
The Ohio State University
Columbus, OH

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Executive Summary

The purpose of this paper is to discuss research findings focused on the identification of factors affecting the adoption of soil conservation practices and to apply this body of knowledge to the amelioration of groundwater contamination problems. The goal of the paper is to use knowledge generated from soil erosion studies to make suggestions for the development of a program designed to reduce the incidence of groundwater contamination.

A number of factors which have been examined in the context of adoption of soil conservation practices are discussed. Individual characteristics of potential adopters, farm structure variables, psychosocial factors and institutional constraints are the types of variables examined. It is argued that the best predictors of adoption of soil conservation practices are farm structure and institutional variables.

Similarities and differences between soil erosion and groundwater contamination produced by agricultural sources are outlined. It is concluded that the two types of environmental degradation are the product of similar causal factors. It is argued that resolution of both types of pollution will require changes in human behavior. It is further argued that findings derived from research focused on the adoption of soil conservation practices have utility for understanding the adoption of groundwater protection practices.

Two theoretical perspectives which have been used to explain adoption behaviors are examined in the context of their utility for understanding adoption of soil conservation practices. The two theoretical orientations examined are diffusion theory and the farm structure-institutional constraint perspective. The diffusion concepts examined are as follows: awareness, relative advantage, compatibility and complexity. The farm structure-institutional constraints concepts discussed are as follows: characteristics of the farm enterprise, financial conditions of the potential adopter, land tenure, past and present investments in technologies, national and international production and marketing systems, and government farm and conservation policies.

Suggestions are made regarding strategies for implementing a groundwater protection program. It is argued that such a program should be formulated using elements of the diffusion and the farm structure-institutional constraints theories. It is suggested that a combination of strategies should be employed to encourage adoption of groundwater prevention practices. It is argued that both voluntary and coercive approaches should be used to encourage adoption.

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Introduction

Groundwater contamination is a socio-environmental issue of concern in the U.S. While the amount of degraded groundwater is relatively small in proportion to the total resources available (Henderson, 1987; Page, 1987_a), it is frequently located near densely populated communities which use these sources for drinking water. It has been estimated that 95 percent of rural households and at least 50 percent of the total U.S. population rely on groundwater for household use (Page, 1987_a). As more groundwater becomes contaminated, the threat to health in both urban and rural areas will increase.

While groundwater contamination poses a problem for urban people, it is particularly problematic for rural residents. Most nonmetropolitan people are dependent on groundwater for household use and alternative sources of drinking water are not readily available. If wells become contaminated with pesticides, nitrate (NO_3) or ammonium (NH_4), which are the most frequent chemical contaminants in rural areas (Anderson, 1987), rural people are often forced to use bottled water for drinking. Reliance on bottle water creates an additional economic cost for rural people and is an inconvenience.

Ultimately, society has two options for addressing groundwater contamination. Degraded groundwater resources must be reclaimed or efforts must be initiated to prevent contamination from occurring. Given the high cost of reclamation (Christensen, 1983; Christensen and Norris, 1983; Clark, 1987), it is highly unlikely that decontamination will be a cost-effective approach in the near future for some toxic substances (Page, 1987_a). The most prudent alternative, at least in the short-run, is to protect critical groundwater resources from being degraded.

While it is easy to conclude that prevention is the most rational approach for protecting important and highly sensitive groundwater supplies, the implementation of a strategy to protect groundwater resources is extremely difficult. Potential polluters must be motivated to change behavioral patterns to reduce degradation. Contrary to popular belief, human behavior is not easily modified unless there are significant personal rewards associated with changing behavior (Bandura, 1977; Rogers, 1983; Turner, 1974). Individuals are often reluctant to adopt new behaviors even when adoption will generate rewards for them because they value established modes of behavior more than the benefits received.

Another reason for resistance to behavioral change is lack of awareness on the part of polluters. Often people are not aware that they are contributing to environmental degradation. If land operators are made aware of their contribution to the problem, they may become more willing to change behaviors. This assumes that the behavioral change does not result in significant costs for the potential adopter.

It must be recognized that increased awareness of groundwater contamination problems may not result in the adoption of groundwater prevention practices. Polluters are often business persons who are motivated to maximize short-run profits and profit-making may take precedence over environmental concerns. It is very difficult to motivate business persons to adopt water conservation behaviors which have the potential to reduce profits.

The problems noted above are not unique to groundwater contamination. Similar problems have been observed for pollution caused by soil erosion, however, much more is known about pollution caused by soil erosion than about groundwater pollution. Subsequently, the literature focused on soil erosion will be examined to gain insight to potential solutions to groundwater problems.

Similarities and Differences Between Soil Erosion and Groundwater Problems

Similarities

The most significant similarity between surface pollution caused by soil erosion and groundwater contamination from agricultural sources is that both are strongly influenced by human activity. While there is natural contamination of surface and subsurface water resources, much of the contemporary concern about degradation of soil and water resources is the product of human intervention. Human beings control land resources and make decisions about agricultural practices used on the land which significantly affect the level of environmental degradation.

Another similarity between both types of environmental degradation is that they are the result of nonpoint pollution. Identification of specific polluters is problematic, given the multiple sources of contamination. The difficulty of identifying polluters makes it problematic to employ nuisance laws to stop degradation or to force offenders to compensate people who have been damaged (Henderson, 1987). The result of the inability to effectively monitor soil erosion and groundwater contamination is that farmers can treat both types of pollution as an externality of production with very low probability of being penalized by society.

Socially acceptable levels of soil erosion and groundwater contamination have not been clearly established. It is very difficult to define what is an acceptable level of soil erosion and groundwater pollution, since society has not established criteria for assessing the problem. The issue is compounded by

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the fact that society has multiple objectives. Maintenance of high levels of agricultural productivity frequently takes precedence over environmental concerns. In some situations, higher levels of soil erosion and groundwater pollution may be defined as being acceptable to maintain high levels of food and fiber production. A goal of zero soil erosion and groundwater contamination is not realistic in a complex society such as the U.S. (Anderson, 1987).

Soil and groundwater resources can be degraded to the point that future use is greatly impaired. Soil resources can become so depleted that food and fiber production are adversely affected even with the addition of chemicals and the application of mechanical technologies (Pimental, et al., 1976). Groundwater may become so contaminated that it is not useful for any purpose without remedial treatment (Page, 1987). Loss of future use of land and water resources should be considered in the assessment of present value. Soil and groundwater resources which are relatively low in value at the present time may become extremely valuable in the future. Public investments in water and soil conservation greater than the present value of the resources perhaps may be justified on the basis of protecting options to use the resource in the future.

The incidence of soil erosion and groundwater contamination is affected by regional variability in climate, topography, geology, population characteristics and occupational activities. Physical characteristics of farm land and climate affect rates of soil displacement and rapidity of water movement into aquifers (Page, 1987_a). These factors influence the types of crops produced, methods of production employed, and the types of chemicals applied. The impact of social factors on environmental degradation must also be considered because they influence the distribution of population and occupations. Less densely populated areas in certain regions of the country tend to have greater feed grain and food grain production which means that agriculturally-related soil erosion and groundwater contamination will be greater.

Both soil erosion and groundwater contamination contribute to off-site damages. Members of society are affected who do not contribute directly to these problems. Contamination of groundwater from agricultural sources may result in loss of access to local water supplies by nonfarm people. These individuals may also be denied use of surface water due to contamination by soil erosion from cultivated farmland (Easter, et al., 1983; Miranowski, 1983; Napier, 1987; Napier, et al. 1983; Swanson, et al., 1986). Rural highways, road ditches, lakes and waterways may become silted by displaced topsoil and must be cleared using public resources (Halcrow, et al., 1982; Napier, et al., 1988_b; Napier, et al. 1983). Urban residents are also affected by environmental degradation created by agriculture. All of the off-site costs discussed above affect urban people to some extent. Urbanites must also assume additional costs associated with investments made in public water treatment facilities. Residents of all large cities must allocate extensive resources to construct facilities to make contaminated groundwater and surface water potable.

Another problem associated with both soil erosion and groundwater contamination is that the social, economic and environmental costs of soil erosion and groundwater pollution are difficult to quantify. Data seldom exist to link degradation of water quality with specific socio-economic costs. For example, loss of aesthetic quality of surface water resources due to soil erosion of farmland has been recognized (Lovejoy and Napier, 1986; Napier, et al. 1983; Napier, 1988_a; Swanson, et al., 1986) but data to assess costs have not been collected. Information about the economic costs associated with water purification (Forster, 1987; Clark, 1987) have been collected, however, better measurement will be required before all costs can be quantified. Many of the adverse consequences of soil erosion and groundwater pollution are not visible. Harmful chemicals in streams and reservoirs cannot be seen (Pimentel, 1987). People ingest well water containing toxic substances without being aware contamination is present. A significant proportion of urbanites are so far removed from the natural environment that they are not aware of pollution (Schnaiberg, 1980).

Both soil erosion and groundwater pollution can contribute to human health problems. Even though the effects of some inorganic and organic compounds are not well known at the present time (Page, 1987_a), it is acknowledged that toxic substances in surface and ground water supplies are harmful to human health. Fortunately, the concentrations of toxic substances in most water supplies are seldom high enough to create health problems. Nitrates from agricultural sources occasionally reach levels in urban water supplies to cause concern. Local officials have issued warnings to parents of small children to refrain from feeding infants contaminated water. Pesticides and nitrates in rural well water pose a potentially serious health problem in some areas of the country.

Adoption of soil conservation and groundwater protection practices may result in the loss of income for land operators. Modern farmers frequently use highly erosive tillage practices and apply large quantities of fertilizers to maintain high levels of productivity. Large-scale agricultural systems require extensive use of pesticides to control weeds, insects and fungi to achieve the highest level of output (Schnaiberg, 1980). Reduction of soil erosion and groundwater pollution may require use of less disruptive tillage systems and fewer chemical in-puts which may result in lower food and fiber output. Loss of productivity per acre may not be off-set by reduced costs of in-puts and the net effect may be reduced income for farmers. Since most farmers are business persons who wish to maximize short-run profits (English and Heady, 1980; Kraft, 1978; Miller, 1982; Napier and Foster, 1982; Swanson, _et al_., 1986), it is highly likely they will resist adoption of farm practices which may reduce their income.

Soil erosion and groundwater pollution can result in the loss of resale value of land resources. Soil erosion which significantly reduces productivity or adversely affects the aesthetic quality of land holdings can result in loss of resale value (Swanson, _et al_., 1986). Groundwater contamination can also result in loss of resale value, if the land is to be used for housing purposes and wells are required for household water supplies. It is highly unlikely that potential buyers will pay market prices for homesites which do not have safe drinking water available.

Differences

One of the major differences between groundwater contamination and soil erosion is that techniques used to solve one problem may not be compatible with resolution of the other. Conservation practices designed to reduce soil erosion may exacerbate degradation of groundwater resources. Soil conservation practices which reduce the rapidity of surface water run-off will retard soil displacement (El-Swaify, _et al._, 1985; Moldenhauer and Hudson, 1988) but such practices frequently increase water percolation through chemical-rich soils (Moldenhauer, 1987; El-Swaify, _et al._, 1985). Farm chemicals captured by water passing through soil may eventually contaminate groundwater resources (Anderson, 1987). Ultimately, land operators may be required to balance soil conservation with protection of groundwater resources.

Methods used to implement soil erosion control and groundwater protection programs have traditionally been somewhat different. While soil erosion programs have tended to be voluntary in nature, use of several toxic chemicals by agriculturalists has been controlled via regulation. Traditionally, efforts to bring about the adoption of soil conservation practices have relied heavily on education, technical assistance and monetary subsidies by the federal government (Napier, 1987; Napier, 1989; Napier and Forster, 1982). While more recent government-sponsored, soil conservation programs have become more coercive in nature (Napier, 1987; Napier, 1989), they still place great emphasis on voluntary participation. Given the adverse consequences of certain farm chemicals on groundwater resources, regulations have been imposed to ban use of specific chemicals. Other regulatory approaches used to control application of farm chemicals are certification programs, restricted use of certain pesticides and controls on application in specific geographical areas.

The problems associated with assessing liability for soil erosion and groundwater contamination are different. While nuisance laws are the primary means of legally approaching the problem of off-site damages caused by both types of pollution (Henderson, 1987), the difficulty associated with identification of specific sources of agriculturally-induced, groundwater pollution is more difficult than isolating damages caused by soil erosion. Given the state of knowledge of site-specific groundwater movement and hydrologic processes (Anderson, 1987), it is very difficult to prove that a specific individual is contributing to the degradation of groundwater resources. Identification of contributors to soil erosion is difficult and expensive using in-stream monitoring devices and remote sensing but the difficulties of assessing groundwater contamination are more problematic.

The primary responsibility for reducing soil erosion and groundwater pollution varies by political jurisdiction. The off-site damages of soil erosion are often interstate, while most groundwater problems are more localized (Henderson, 1987). Federal agencies have primary responsibility for soil erosion due to the interstate nature of the problem. However, state and local jurisdictions have a major role to play in groundwater protection, since the problem tends to be confined to local areas within states.

The incidence of soil erosion and groundwater pollution varies by geographic region. Some cultivated land in the U.S. has a high rate of erosion but the greatest majority has relatively little. It has been estimated that from 80 to 90 percent of all water-related, soil erosion occurs on about 10 to 15 percent of the cultivated land in the U.S. (Gardner, 1985). In like manner, groundwater contamination tends to be differentially distributed throughout the U.S. Frequently areas of high vulnerability to soil erosion are different from those subject to groundwater contamination. Agricultural regions which have relatively high levels of soil erosion export farm chemicals to people living downstream, while farming areas with little displacement of topsoil tend to contribute to groundwater contamination in the local area.

Knowledge of the factors affecting adoption of management practices to prevent soil erosion and groundwater contamination differs considerably. Extensive research has been conducted during the past 10 years which has been focused on the identification of variables which facilitate or impede adoption of soil conservation practices (Halcrow, et al., 1982; Lovejoy and Napier, 1986; Napier, et al. 1983; Moldenhauer and Hudson, 1988). Unfortunately, relatively little research attention has been focused on factors which affect adoption of groundwater prevention practices.

Summary of Comparisons

Review of similarities and differences between pollution created by soil erosion and groundwater contamination produced by agricultural sources revealed numerous important similarities and several significant differences. The most important similarity between the two types of pollution is that human intervention is the principle cause of both. The behavior of land operators is the primary determinant of soil erosion and groundwater pollution which suggests that reduction of both types of pollution requires modification of human behavior. It must be recognized, however, that motivating people to change behaviors is frequently very difficult, especially when existing behavioral patterns have been shown to produce desired rewards (Bandura, 1977; Ekeh, 1974; Rogers, 1983; Turner, 1974).

To effectively modify human behavior requires extensive knowledge of the factors affecting acceptance of behaviors to be adopted. Unfortunately, research focused on the factors affecting the adoption of groundwater protection practices does not exist. This lack of knowledge makes it very difficult to develop groundwater protection programs.

While very little information exists concerning the relationship of human behavioral factors and groundwater contamination, a very good research base exists to predict adoption of soil conservation practices. Given that soil erosion and groundwater contamination are caused by use of certain types of farming practices, it is argued that research findings focused on the adoption of soil conservation practices will provide insight to theoretical perspectives and variables which may be useful in understanding problems associated with groundwater protection. While information obtained from soil erosion research is not directly transferable to groundwater protection problems, it should provide a starting point for future research and policy endeavors.

Factors Affecting Adoption of Soil Conservation Practices

Numerous variables have been shown to be significantly related to the adoption of soil conservation practices. These factors can be subsumed under several broad categories for discussion purposes: individual characteristics, farm structure factors, psychosocial factors and institutional constraints factors.

Individual characteristics have been repeatedly used to predict voluntary adoption of soil erosion control practices in the U.S. Numerous studies have been conducted using personal characteristics of land operators in hopes of identifying individuals who have a propensity to voluntarily adopt soil conservation practices. The goal of these efforts has been to design soil conservation programs for specific audiences.

Unfortunately, existing findings indicate that individual characteristics have very limited utility for predicting adoption of soil conservation practices. Contrary to social learning theory (Bandura, 1977), farmers who are younger, better educated, more aware of erosion problems, have greater access to information systems and have been exposed to more information about soil conservation do not consistently adopt soil conservation practices (Lovejoy and Napier, 1986; Napier and Forster, 1982; Swanson, *et al.*, 1986).

Social learning theory basically argues that individuals who are exposed to learning experiences which demonstrate the merits of new ideas or practices will have a higher probability of adopting. Social learning theory suggests that younger people with higher levels of education and knowledge of soil conservation problems will have a higher probability of adopting soil erosion control practices because they are more aware of benefits associated with adoption. Unfortunately, empirical evidence does not support such conclusions.

Of particular interest to action agencies are the findings focused on awareness variables. Proponents of the educational approach (social learning perspective) argue that the best strategy for facilitating the adoption of soil conservation practices is through the provision of information to make land operators aware of erosion problems and how erosion can be reduced. Several studies have included measures of awareness and access to information about soil erosion problems (Napier, et al., 1984; Napier, et al., 1988_a, Korsching and Nowak, 1980; Lovejoy and Napier, 1988; Swanson, et al., 1986) and have demonstrated that these factors are poor predictors of adoption behaviors. The findings suggest that access to information and awareness of erosion problems are necessary but not sufficient conditions for voluntary adoption of soil conservation practices to occur. It is highly likely that educational programs alone will have relatively little effect in bringing about greater adoption of soil conservation practices in the U.S.

A variety of other personal characteristics have been examined in the context of adoption of soil conservation practices and a number of factors have been shown to be significantly related with adoption behavior. Unfortunately, the amount of explained variance using such factors has also been relatively low. This means that the utility of these types of variables for predicting adoption of soil conservation practices is limited (Lovejoy and Napier, 1986; Napier and Forster, 1982; Swanson, et al., 1986).

Research findings focused on personal characteristics strongly suggest that attempts to design soil conservation programs for specific audiences on the basis of personal characteristics is probably not appropriate. Land owners who adopt soil conservation practices tend to be heterogenous as a group in terms of personal characteristics (Napier and Lovejoy, 1988). Primary reliance on an educational strategy to bring about adoption of soil conservation practices will probably produce only marginal success.

Farm structure factors have been shown to be significant variables in the prediction of voluntary adoption of soil conservation practices (Halcrow, *et al*., 1982; Lovejoy and Napier, 1986; Napier and Forster, 1982; Napier and Lovejoy, 1988; Swanson, *et al*., 1986). Variables such as gross farm income, acres farmed, acres owned, acres rented, access to farm technologies, farm specialization, debt to equity ratio, past investments in technologies, farm tenure and other farm-related factors affect decision-making about tillage practices used at the farm level.

Access to economic resources is often necessary to adopt soil conservation practices. Farmers who do not have the capital to invest will be prevented from adopting soil conservation practices even though they may have a strong desire to do so (Camboni, 1984; Hooks, *et al*., 1983; Napier, 1988$_c$; Swanson, *et al*., 1986). Many land operators do not have sufficient economic resources to invest in conservation practices even with government cost-sharing.

Past investments in farm technologies can prevent farmers from adopting conservation tillage systems (Carlson and Dillman, 1986; Miller, 1982). Presently owned farm technologies will continue to be used until they must be replaced unless adoption of new technologies will significantly increase farm income. Adoption of new technologies will occur, if the short-run return to investment is very high. However, it is highly unlikely that land operators will shift to new tillage practices which require purchase of costly technologies while equipment purchased in the past are still serviceable. This is especially true for farmers with cash-flow problems (Napier, 1988_c).

Financial hardship can act as a barrier to the adoption of soil conservation practices (Napier, 1988_c). Farmers with high debt to equity ratios will probably be more reluctant to adopt alternative tillage systems, since they cannot afford to increase the uncertainty attached to use of different farming practices. This is especially true for adoption of soil conservation practices, because many of these practices will not produce financial rewards for the individual adopter in the short-run and may not do so even in the long-run (Ervin and Washburn, 1981; Miller, 1982; Mueller, et al., 1985; Putman and Alt, 1987). Farmers are often aware that adoption of many soil conservation practices will not increase farm income (Miller, 1982). They can frequently secure much higher returns through alternative investment options. Investment in conventional farming practices and technologies is often the most secure option because such agricultural approaches tend to maximize production. Conventional practices are also more likely to be approved by agricultural lenders which is another disincentive for adoption of conservation practices.

Farm specialization can affect adoption of specific soil conservation practices (Napier and Lovejoy, 1988). Some soil conservation practices are inappropriate for certain types of farming activities. Adoption of grass waterways, for example, by dairy farmers is not a significant event, since such farmers already produce hay and grass on a portion of their land. However, grain producers may be reluctant to implement any type of land diversion program due to increased cost of tilling around retired land. Grain farmers may be more willing to adopt conservation tillage systems, since such approaches are more consistent with existing practices.

Land tenure has been posited to be significantly associated with adoption of soil conservation practices (Batie, 1986; Ervin, 1986). It has been argued that one of the greatest impediments to adoption of soil conservation practices by tenants has been the inability of renters to "capture" the benefits of investments in soil conservation practices. It has been posited that farmers will not adopt soil conservation practices unless they can derive direct benefits from the conservation investments. Ervin (1986) suggests that long-term agreements may encourage renters to implement soil conservation practices because such contracts assure the tenant access to land resources for long periods of time. Such agreements would make it possible for tenants to benefit from the implementation of soil conservation programs. While these arguments have considerable merit, research by Napier and Camboni (1988_a) suggest that concern for land tenure may be over-stated in Ohio. They observed that land tenure was not significantly related to the adoption of several types of soil conservation practices assessed in the study. They reported that over 90 percent of all farmers interviewed used the same practices on rented and owned land.

Psychosocial factors have been argued to be significantly related to the adoption of soil conservation practices. Perceived profitability of conservation practices, stewardship orientations, attitudes toward government involvement in agriculture, attitudes toward efficiency in decision-making, perceptions of relevance of conservation practices, perceptions of soil erosion as a problem, commitment to environmentalism and many other attitudes have been examined in the context of predicting adoption of soil conservation practices (Bultena and Hoiberg, 1986; Carlson and Dillman, 1986; Hansen, et al., 1987; Halcrow, et al., 1982; Miranowski, 1982; Napier, 1987; Napier and Forster, 1982; Napier, et al., 1986; Napier and Camboni, 1988_a).

Existing research findings reveal that psychosocial attitudes have some utility for predicting adoption of soil conservation practices. Land operators who are more concerned about the environment, perceive adoption of soil conservation practices to be profitable, are more favorable toward government involvement in farming, perceive themselves to be stewards of the land, perceive their land to be eroding, perceive soil conservation practices to be relevant to their farming operation and perceive soil conservation practices to be beneficial tend to adopt soil conservation practices more often. These findings are consistent with research expectations, however, the amount of explained variance in the computed models is relatively low.

An important consideration in the adoption process is perceived profitability. Research has shown that many farmers perceive that adoption of soil erosion control practices can produce profits for people who use them (Napier, et al., 1988_a; Napier and Lovejoy, 1988). However, land operators holding such perceptions are frequently aware that adoption of soil conservation practices would not be profitable for them because they would have to invest in new technologies, retire valuable land from production, change tillage systems, and develop new farming skills. Such investments to implement a soil conservation program would outweigh the benefits derived from the adoption. Land operators holding such perceptions may also elect not to adopt soil conservation practices because they have more profitable investment alternatives. Thus,

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creation of a positive orientation toward profitability of soil erosion control practices will not guarantee adoption.

The psychosocial findings suggest that positive attitudes toward soil conservation is a necessary but not sufficient condition for adoption to occur. Evidence to date indicates that many land operators have developed very positive attitudes toward soil conservation practices but have not adopted recommended practices. These finding suggest that action programs designed to facilitate the adoption of soil conservation practices cannot rely solely on strategies to make land operators positive toward conservation issues.

Institutional constraint factors is an area of soil conservation research which has emerged recently. Several researchers (Berardi, 1987; Buttel and Swanson, 1986; Lovejoy and Napier, 1988; Napier, 1988$_c$; Osteen, 1987; Swanson, *et al*., 1986) have argued that institutional factors, such as government farm programs, federal conservation programs and general economic conditions in the society and the world, affect adoption of soil conservation practices at the farm level.

Proponents of the institutional constraints perspective suggest that government agricultural programs designed to maintain farm income act as impediments to adoption of soil conservation practices. It is suggested that farm programs act as incentives to maximize production. Government payments are calculated on the basis of output per acre and maximization of production will produce the largest government payment. History suggests that the most productive farming system in the U.S. is often the most erosive and that farmers are willing to accept higher rates of land degradation to maintain high productivity. While these problems will be partially corrected by the linkage

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of commodity and soil conservation legislation in the Food Security Act of 1985, it is highly likely that commodity programs will continue to act as incentives for farmers to maintain the highest levels of production possible.

Federal conservation policies can affect the adoption of erosion control practices. Subsidies allocated to land owners who adopt soil control practices have been shown to motivate farmers to participate in soil conservation efforts (Napier and Forster, 1982; Napier, 1989). For example, the Conservation Reserve Program included in the Conservation Title of the Food Security Act of 1985 has successfully removed more than 20 million acres of highly erosive land from production and more than 20 million additional acres has been authorized for retirement (Napier, 1989).

The structure of the present agricultural system impedes voluntary adoption of soil conservation practices (Buttel and Swanson, 1986; Napier, 1988$_a$; Swanson, et al., 1986). The present farming system is highly competitive and farmers who survive must maintain high levels of production (Miller, 1982). Technology-intensive practices combined with row-crop production tend to maximize food and fiber production but they also exacerbate erosion. Also, the competitive nature of the present agricultural system encourages the cultivation of marginal land which is often highly erosive and should never be brought into production. It is highly probable that a significant amount of marginal land in production today would not have been farmed, if pressure on farmers to maximize production had not been so great (American Farmland Trust, 1984; Berardi, 1987; Batie, 1982; Ogg, 1983; Osteen, 1987; Reichelderfer, 1984; USDA, 1982).

Research findings from a recent study in Ohio revealed that institutional factors influenced voluntary adoption of soil conservation practices (Camboni, et al., 1989; Napier and Lovejoy, 1988). Data collected from farmers operating

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land in a highly erosive watershed revealed that participation in government farm programs affected adoption of soil conservation practices and knowledge of government soil conservation programs. This finding was explained in the context of greater awareness by farmers who participated in such programs (Camboni, _et al._, 1989). It is highly likely that future research using institutional factors will substantially increase the explained variance in adoption of soil conservation practices.

The primary implication of the institutional findings for design and implementation of soil conservation programs is that new conservation initiatives must take into consideration existing government policies and programs which can negate the benefits of conservation efforts (Lovejoy and Napier, 1988). It is highly likely that federal policies designed to maximize food and fiber production contribute to soil erosion problems.

Summary of Factors Affecting Adoption

The research findings reviewed for this paper suggest that farm structure and attitude factors are the best predictors of adoption of soil conservation practices at the farm level. The best predictors of adoption behaviors are farm speciality variables. Evidence suggests that the development of positive attitudes toward conservation and environmental issues is a necessary but not sufficient condition for adoption to occur.

Individual characteristics have been shown to be poor predictors of voluntary adoption of soil conservation practices. Social learning variables have been demonstrated to have little utility in explaining voluntary adoption of soil conservation practices.

Preliminary evidence suggests that institutional constraints are useful predictors of conservation behaviors at the farm level. Inclusion of institutional factors in future research may significantly improve the amount of explained variance in statistical models used to predict voluntary adoption of soil conservation practices. Institutional factors frequently impede adoption of soil conservation practices because land operators are not able to influence macro-level variables (Buttel and Swanson, 1986; Swanson, et al., 1986).

Theoretical Models Used to Explain Adoption of Soil Conservation Practices

The Traditional Diffusion Model

The theoretical orientation most frequently used to guide research focused on the adoption of soil conservation practices is the diffusion of innovations perspective (Brown, 1981; Rogers, 1983; Taylor and Miller, 1978). The traditional diffusion perspective basically asserts that adoption behavior is strongly influenced by access to information and learning experiences. Primary reliance is placed on communication in the diffusion process. It is argued that when people are exposed to innovations which will produce desired benefits, they will adopt.

The diffusion model suggests that several necessary but not sufficient conditions must be satisfied before adoption can occur. The perspective posits that a potential adopter must be made aware that a problem exists before he/she will consider changing behaviors. The potential adopter must also perceive that a socially acceptable solution exists to resolve the identified problem. Once potential adopters are made aware of possible solutions, they will seek information to facilitate the decision-making process. Potential adopters evaluate information and formulate attitudes toward the object being evaluated. How the object being evaluated is perceived will strongly influence the adoption decision. Ultimately, the potential adopter must decide on a course of action which is most appropriate for his/her situation.

Several important diffusion concepts affect the outcome of the decision-making process. The most important diffusion concepts for soil and water conservation programs are as follows: awareness, relative advantage, compatibility, and complexity.

Awareness is defined as the state of being conscious of problems and of possible solutions. Potential adopters must recognize that environmental problems and solutions exist before they will consider changing behavioral patterns. There is no purpose in being concerned about problems, if there is no way of solving them.

There are many sources of information which may be used by potential adopters. People in industrial societies such as the U.S. frequently use mass media systems to become aware of action options. However, in-depth knowledge of specific alternatives is most often secured from personal contact with knowledgeable people or from technical sources such as journals and books. Regardless of the methods used to disseminate information, potential adopters must have access to information for decision-making.

Relative advantage refers to the benefits to be received from adoption of new action options compared with existing practices. Potential adopters assess alternative actions in the context of improvements over practices presently being used. If an action option will produce greater benefits than those presently in use at no additional cost, adoption will be considered. If the action option will not produce greater benefits, there is no relative advantage associated with

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adoption. Most people use mental cost-benefit assessments to determine if an action option is worthy of serious consideration (Rogers, 1983).

Compatibility refers to how consistent new practices are with established behaviors. If an action option disrupts established patterns too extensively, it will tend to be resisted even though it may generate benefits which are highly valued. Disruption of established modes of behavior is considered a cost in the decision-making process. Action options which complement existing practices will tend to be more quickly adopted.

Complexity refers to the level of difficulty associated with understanding and using something being considered for adoption. If something is very difficult to understand or to use, adoption is less likely to occur. Some soil conservation practices are very difficult to understand and to implement at the farm level. Such practices are less frequently adopted.

Application of the Diffusion Model to the Adoption of Soil Conservation Practices

Reduction of soil erosion nearly always necessitates change in management practices at the farm level. However, farmers are often reluctant to change established production systems because existing practices have been shown to produce desirable outcomes. Unless it can be clearly demonstrated that adoption of soil conservation practices will increase productivity, land operators will be reluctant to adopt. Unfortunately, it is often difficult to demonstrate profitability of soil conservation practices (Mueller, et al., 1985; Putman and Alt, 1987). It must also be recognized that some soil conservation practices which may be profitable may not be appropriate for certain farm operations due

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to farm speciality. This suggests that demonstration of the relative advantage of soil conservation practices over conventional farming systems is problematic.

Evidence to date suggests that land operators in the U.S. are knowledgeable of the causes of soil erosion. They are aware that soil erosion is problematic at the national, state and local levels. Also, many farmers are aware that their land is eroding. Most farmers are aware of techniques to control soil erosion. All of these findings suggest that knowledge of erosion problems and awareness of techniques to resolve them does not appear to strongly influence adoption of conservation practices. Even though many farmers are aware of soil erosion on their land, they continue to use tillage practices which exacerbate erosion. Research to date strongly suggests that the provision of additional information about soil conservation will probably have very marginal impact on the problem (Napier, 1988$_a$; Napier, 1987; Napier, et al., 1988$_a$; Swanson, et al., 1986).

Some soil conservation practices are incompatible with existing tillage systems. Adoption of no till, for example, frequently necessitates extensive investment in new farm technologies, if traditional tillage practices are being used. The costs associated with adopting new tillage systems may be prohibitive (Carlson and Dillman, 1986). Other soil conservation practices are basically compatible with traditional tillage systems, such as conservation tillage (minimum tillage with 1/3 biomass on the land at planting time). A large portion of conventional farming equipment can be used in conservation tillage systems but fall plowing is usually prohibited.

Adoption of some soil conservation practices necessitates investment in new farming skills by the land operator, if the benefits of adoption are to be achieved. New skills are required because some soil conservation practices are difficult to use. For example, no till farming requires appropriate application of chemicals and timing of treatments. Skill levels may differentiate adopters of soil conservation practices from nonadopters.

While the traditional diffusion perspective should be applicable to the voluntary adoption of soil conservation practices at the farm level, empirical research has demonstrated repeatedly that diffusion-type variables are relatively inconsequential in the explanation of variance in the adoption of such practices. However, the theory has been shown to be predictive of participation in government-sponsored, soil conservation programs which have economic incentives attached to adoption (Bouwes and Lovejoy, 1980; Napier, et al., 1988_a; Napier and Camboni, 1988_b; Camboni, et al., 1989). These studies strongly suggest that diffusion variables are only predictive of adoption behaviors in situations where potential adopters have a high probability of deriving direct benefits from adoption and the benefits are clearly recognizable. Most farmers are aware that adoption of soil conservation practices without government subsidies is not profitable.

Appropriateness of the Diffusion Model to the Adoption of Groundwater Protection Practices

While the traditional diffusion perspective has been shown to have limited utility for predicting voluntary adoption of soil conservation practices, it will probably be quite useful for developing programs designed to reduce the incidence of groundwater contamination. The reason for this assertion is that an important difference exists between soil erosion and groundwater contamination. Farmers who adopt groundwater protection practices may receive direct benefits in the form of safe drinking water. They seldom benefit directly for voluntary adoption of soil conservation practices. In fact, farm income may be reduced by adopting certain soil conservation practices.

Land operators can export water-borne pollutants created by soil erosion to other members of society with considerable immunity. Farmers are seldom threatened by contaminants in surface water and are hardly ever required to pay for damages created by farm chemicals and sediments which they contribute to surface waterways. Most of the off-site costs of soil erosion are borne by nonfarm people. Thus, off-site damages are not perceived to be costly to the agricultural polluter.

Groundwater contamination, however, can adversely affect the land operator and his/her family. Threats to family health can be a very strong incentive for farmers to adopt practices which will protect the quality of groundwater resources. Adoption of groundwater protection practices will probably occur even if use of such practices will slightly reduce farm profits. The minor loss of farm profits would probably be perceived to be small payment for reduced health risk. This assertion is predicated on the assumption that land operators are made aware of the linkage between agricultural practices and groundwater contamination.

The threat of groundwater contamination to family health could also prove to be a strong incentive for land owners to control farming practices of tenants. Use of inappropriate farming practices by tenants could result in contamination of drinking water of land owners. Concern for health should encourage greater participation by owners in the management of land resources operated by tenants.

The soil erosion literature strongly suggests that farmers are aware of pollution caused by soil erosion. However, it is highly unlikely that many farmers are aware of the contamination of subsurface water supplies from agricultural sources. It is doubtful that farmers are familiar with the hydrologic cycle, understand the physics of groundwater contamination and are knowledgeable of the linkage between farming practices and the contamination of groundwater supplies. It is also possible that many land operators are unaware that their household water supply is vulnerable to contamination by agricultural pollutants. Thus, the awareness concept of the diffusion model should be relevant to understanding adoption of groundwater contamination prevention practices.

Awareness programs were initially successful in facilitating adoption of soil conservation practices in the 1920s and 1930s when farmers were unaware of measures to prevent soil erosion. Similar approaches may be useful in facilitating adoption of practices to reduce the threat of groundwater contamination. However, sole reliance should not be placed on the provision of information.

The adoption literature strongly suggests that conservation practices must be compatible with existing farming systems, if they are to be readily adopted at the farm level. This finding suggests that programs designed to reduce groundwater contamination should incorporate recommended conservation practices which are compatible with existing farming methods. Conservation programs which emphasize wholesale modification in farming systems and purchase of new technologies will be strongly resisted by agriculturalists. Consideration should be given to advancing farming systems which emphasize more careful application of farm chemicals and better timing of applications. Not only would the environment benefit from reduced chemical use but farmers may be able to offset some possible production losses by lowering input costs.

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Lastly, the diffusion model and the soil conservation literature noted above suggest that techniques to prevent contamination of groundwater resources must be relatively simple to implement. Use of existing educational infrastructures such as the Soil Conservation Service and the Cooperative Extension Service should facilitate removal of the skill barrier to adoption of groundwater protection practices. The soil conservation literature suggests that farmers are willing to develop new farming skills, if the rewards for doing so are adequate to compensate them for their efforts (Napier and Lovejoy, 1988).

The Farm Structure-Institutional Constraint Perspective

The farm structure-institutional constraint perspective basically asserts that structural conditions of the farm enterprise and macro-level institutional conditions in the society affect adoption of soil conservation practices. This perspective argues that farmers who do not have access to economic resources to adopt soil conservation practices will be unable to implement soil conservation programs even though they may desire to do so.

National and international economic conditions can act as barriers to the adoption of conservation practices (Swanson, et al., 1986). Farmers who have high debt to equity ratios may be unable to divert scarce capital for conservation efforts (Napier, 1988_b). International and domestic demand for agricultural products can act as incentives to use short-term planning horizons which emphasize maximization of production.

The present agricultural system in the U.S. is oriented toward large-scale production and technology-intensive farming practices. Such a system is very productive but it is also highly erosive of land resources. Agricultural institutions implement policies which support the continuance of the system at the expense of the environment.

Permanent solutions to soil erosion problems cannot ignore institutional conditions such as those outline above. To attack soil erosion problems solely from the perspective of changing the individual farmer is counter productive and will probably not be successful. Long-run reduction of soil erosion problems will necessitate both behavioral change on the part of farmers and structural change in the agricultural system. The latter will be the most difficult to accomplish.

Appropriateness of the Farm Structure-Institutional Constraint Perspective to the Adoption of Groundwater Practices

It is highly probable that the farm structure-institutional constraint perspective will have considerable utility for understanding adoption of groundwater protection practices. Several of the variables included in the theoretical orientation should affect adoption of groundwater protection practices in the same manner as they affect adoption of soil conservation practices.

Government farm programs will probably act as barriers to adoption of groundwater protection practices as they do for soil erosion control practices. Government farm programs will probably continue to motivate land operators to maximize production and to exploit soil and water resources.

Macro-level economic and market conditions will probably act as barriers to adoption of groundwater protection practices as they have for soil conservation practices. The present agricultural system is based on an orientation which stresses increasing size and complexity of farming operations. Land operators who do not use conventional farming practices combined with chemical-intensive farming systems increase the risk of being forced out of farming (Napier, 1988_c). Farmers are under great pressure by the production system to increase output and the only means available for many to do so is through increased energy-intensive mechanical input, and the cultivation of marginal land. Such practices tend to degrade natural resources, but it is highly probable that farmers will continue to be more concerned about survival in the competitive production system than about environmental impacts of their farming practices.

Government-sponsored, soil conservation policies must be taken into consideration during the development of a comprehensive groundwater protection program. It is highly likely that effective campaigns to bring about the adoption of certain types of soil conservation practices at the farm level will exacerbate groundwater pollution. Government conservation policies must be made consistent which suggests that representatives of society will be forced to define what levels of surface and subsurface pollution are socially acceptable. It is highly probable that protection of groundwater resources will be impossible without coordinating groundwater programs with soil erosion control efforts. Some decision-making body must ultimately determine what resource will be permitted to be degraded and to what extent.

Land tenure has been shown to impede the adoption of soil conservation practices because renters have very few ways of capturing the returns to investments made in conservation practices (Batie, 1986; Ervin, 1986). It is highly likely that land tenure will act as a barrier to the adoption of groundwater protection practices for similar reasons. Unless land owners become informed about the threat of groundwater contamination and insist that tenants adopt groundwater protection practices, contamination will probably occur. Tenant farmers will not be constrained by groundwater contamination on rented acreage unless owners inform them that use of farming practices which threaten groundwater resources will not be tolerated. The potential loss of access to land for farming purposes may result in the adoption of groundwater protection practices by tenant farmers. Personal attachments to the land owner may also facilitate adoption of groundwater protection practices by tenants because they would not wish to harm the owner. In situations where personal attachments to the land owner do not exist and the tenant does not depend on the same aquifer for household water supply, formal leasing arrangements to ensure environmental quality may be necessary. Contracts may be enacted to ensure that the quality of groundwater is protected.

Conclusions

The review of the existing literature focused on the voluntary adoption of soil conservation practices and the theoretical perspectives hypothesized to be applicable to the adoption of conservation practices suggest several avenues for implementing groundwater protection programs in the U.S. Some of the elements are voluntary, while others tend to be coercive in nature. It is highly likely that a successful groundwater protection program will require both voluntary and coercive approaches.

One approach is to use an educational program designed to inform land operators of the threat to their well-being and the future use of groundwater resources, if pollution continues. Information programs designed to demonstrate the direct benefits of adopting groundwater protection practices by land

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operators will probably be rewarded by changes in behavior. However, before effective educational programs can be implemented a research base must be developed to ascertain the existing knowledge level of farmers and other rural residents concerning groundwater contamination problems. Information needs of the client groups must be established and educational programs targeted to specific user groups.

Benefits such as protection of health status, reduced in-puts to the production system and maintenance of resale value of land resources should be emphasized in educational materials. If data exist to demonstrate that adoption of groundwater protection practices will not adversely affect food and fiber production, such information should be very useful for convincing farmers to adopt.

A very important issue to be considered in the development of a comprehensive groundwater protection program is monitoring. Research should be conducted on a long-term basis to document the nature of the groundwater pollution problem and the impact of groundwater protection practices on the severity of the problem. Linkage of health problems with groundwater contamination from agriculture would strengthen the information component discussed above.

Another method of convincing farmers to adopt groundwater conservation practices is through the use of economic incentives. Evidence derived from research focused on the adoption of soil erosion control practices suggests that farmers are frequently reluctant to adopt conservation practices without economic subsidies (Bouwes and Lovejoy, 1980; Napier and Forster, 1982). Consideration should be given to extending existing conservation programs such as the Conservation Reserve Program to include protection of critical groundwater resources. The development of farm plans to comply with Conservation Compliance components of the Conservation Title of the Food Security Act of 1985 should take into consideration protection of critical groundwater resources.

Research focused on the adoption of soil conservation practices demonstrates clearly that farmers can be "bought." Farmers can be convinced to adopt groundwater protection practices via government subsidies and rents. Leasing of farm land to prevent the use of farming practices which will degrade groundwater resources may be a cost-effective strategy in the long-run on recharge areas of critical aquifers. An alternative approach would be the purchase of farming rights or the purchase of all land rights by the state to permanently protect critical groundwater recharge areas. The latter option would be the best strategy because land use could be controlled in the future. The long-run cost of land purchase would probably be less than lease arrangements. It may be necessary to formulate Groundwater Preservation Programs at state and local levels in the future.

It is highly probable that Congress will have to assume an important role in the formation and implementation of a comprehensive groundwater protection program. One of the primary reasons the Federal government will be required to act is that local governments do not have the economic and human resources to effectively address the problem. A groundwater protection program similar to the Conservation Reserve Program will be very expensive. Long-term lease arrangements, purchase of cropping rights or purchase of all property rights will be expensive even if only very important aquifers are protected using this approach.

Ultimately, government agencies will be forced to address the issue of what constitutes socially acceptable levels of environmental degradation. Pollution of surface water resources from soil erosion must be evaluated in the context of groundwater contamination. The political process must determine what levels of degradation will be acceptable for both types of pollution. Some groundwater resources will be degraded and some political entity must determine which aquifers will be permitted to be contaminated and to what level. These are political decisions which must be considered by policy making entities such as Congress.

Congress may also have to make some hard decisions in the not too distant future relative to redefining property rights. Under present law, the concept of nuisance is the primary means of stopping soil erosion and groundwater contamination. Given the problems associated with identifying nonpoint polluters, consideration should be given to alternative methods of encouraging land owners to use conservation practices. One method would be forcing all land operators to develop and implement an approved Natural Resources Conservation Plan, if food and fiber for the market economy are to be produced on the farm. Failure to comply would be easily recognized and result in the administration of punishment.

Given the state of scientific knowledge concerning the physics of soil erosion, conservation plans can be developed to ensure that socially acceptable levels of pollution are achieved. Penalties for noncompliance should not be tied to loss of government farm payments, since not all land operators participate in such programs (Napier, 1989). Significant economic penalties for failure to comply with the conservation plan should be applied regardless of the farmer's involvement in government farm programs. Such policies should be an incentive to comply with environmental standards. Once additional scientific knowledge has been generated in the area of groundwater protection, an integrated Natural

Resources Protection Program could be implemented which would optimize conservation of both soil and groundwater resources.

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Appendix 1

Definition of Terms

Rewards are defined as goods, services and recognitions that an individual receives for participating in societal activities. Rewards are defined as anything a person perceives to be desirable. Rewards may be monetary and nonmonetary in nature.

Voluntary adoption refers to adoption of any soil conservation practice without government subsidies. It is argued that subsidized adoption is not totally voluntary even though the land operator may choose not to participate.

Individual factors are defined as socio-demographic characteristics of farm operators such as age, education achievement level, access to information sources, access to learning experiences, length of time engaged in farming, length of residence in community, number of contacts with conservation agencies, and number of contacts with extension agents.

Farm structure factors are defined as characteristics of the farm enterprise such as the number of acres usually cultivated, number of acres usually rented for agricultural purposes, number of acres owned, farm specialization, debt to equity ratio, and past investments in farm technologies.

Psychosocial factors are defined as attitudes held by individual land operators such as perceived profitability, stewardship orientations, attitude toward government involvement in farming, attitude toward efficiency, perceptions of relevance, perceptions of soil erosion as an environmental problem, attitude toward environmentalism, attitude toward farming as an occupation and attitude toward risk.

Institutional constraints are defined as policies and programs to solve collective problems such as government farm programs and policies, conservation policies and programs, and general economic conditions in the society.

Risk is defined as the probability of receiving benefits or internalizing costs from actions taken. In the context of adoption of conservation practices, farmers do not wish to increase the probability of loss due to adoption and use of conservation practices.

Social learning theory is a theoretical perspective which has its basis in behaviorism. The theory argues that human behavior is the product of learning experiences which affect future behaviors. Behavioral modification is achieved via exposure to new information and experiences. Behaviors which have been demonstrated to be rewarding in the past will tend to be repeated as long as rewards are forthcoming. The unit of analysis of this theoretical perspective is the individual.

The farm structure-institutional constraints theoretical orientation is an eclectic perspective which combines farm enterprise concepts with macro-level institutional arrangements to explain adoption of soil conservation practices. This theoretical perspective asserts that individual behaviors are partially governed by forces beyond the individual actor's ability to control.

Appendix 2

Suggestions for Implementing Groundwater Protection Programs

The research findings and theoretical perspectives discussed in this paper have implications for the development of strategies to implement a comprehensive program to protect groundwater resources from agricultural pollution. A successful strategy will necessitate voluntary and coercive components.

1. Educational programs should be developed to inform land owners of the threat to health from groundwater contamination by farm chemicals. Direct benefits associated with adoption of groundwater protection practices should be demonstrated. Development of effective educational approaches necessitates the production of extensive research findings focused on the information needs of farmers and sources of information. Exploration of appropriate methods of disseminating information will be required for this approach to be successful.

2. Programs should be designed and implemented to ensure that land operators' develop positive attitudes toward groundwater protection. Environmental education programs should be useful in removing this barrier to adoption.

3. Methods should be devised to make it possible for land operators with limited economic resources to implement groundwater protection programs. It will probably be necessary to subsidize adoption of groundwater protection practices.

4. Recharge areas of critical aquifers should be protected from degradation by agricultural pollution. Purchase of cropping rights or purchase of all land rights may be required to permanently protect critical groundwater resources. Such action will require intervention by political representatives of the society.

5. Technical assistance should be provided to land operators to facilitate implementation of groundwater protection programs. Agencies such as the Soil Conservation Service and the Cooperative Extension Service should be involved in this type of service activity.

6. National environmental and production policies should be made to complement the other. National production goals and national environmental goals should be clearly specified in the context of achievable outcomes. It is unlikely that existing levels of food and fiber production can be maintained, while simultaneously protecting groundwater quality.

7. Programs should be explored to use scientific knowledge to develop a comprehensive national Natural Resources Protection Program targeted to land operators who produce food and fiber for the market economy.

8. Consideration should be given to expanding existing soil conservation programs to include groundwater protection components. Penalties associated with the programs should not be linked to commodity payments but result in substantial economic sanctions.

Appendix 6

Summary of Necessary But Not Sufficient Conditions For Adoption of Soil Conservation Practices

1. Creation of environmental awareness among land operators.
2. Creation of positive attitudes toward soil erosion control.
3. Removal of economic barriers to adoption.
4. Removal of technical barriers to adoption.
5. Removal of institutional barriers to adoption.
6. Creation of national policies to encourage adoption.

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Appendix 3

Summary of Similarities Between Soil Erosion and Groundwater Contamination

1. The result of farming activity.
2. Forms of nonpoint pollution.
3. Difficult to identify polluters.
4. Damages are obscure.
5. All members of society can be affected.
6. Pollution treated as externality of production.
7. Lower priority than production of food and fiber.
8. Contribute to soil and water degradation.
9. Affected by regional variability of soils, climate and topography.
10. Affected by regional variability of farming practices and social factors.
11. Costs are difficult to quantify.
12. Can affect human health.
13. Resolution can cost farmers income.
14. Lack of treatment can reduce resale value of farms.

Appendix 4

Summary of Differences Between Soil Erosion And Groundwater Contamination

FEATURE	SOIL EROSION	GROUNDWATER CONTAMINATION
Off-farm impacts	Often interstate	More localized
Administrative responsibility to address problem	Federal agencies authorities	State and local
Liability assessment	Difficult	Very difficult
Variation in incidence by geographic region	Depends on land erodibility and farming practices	Depends on hydrogeology, soils, and farming practices
Farming practices employed to address problem	No till and minimum tillage practices combined with filtering systems (filter strips, grass borders, etc.)	Modification of chemical application systems
Degree of regulation in addressing problem	Voluntary (education, technical assistance, and subsidies)	Regulatory (pesticide regulation and application restrictions)
Knowledge base on behavior	Extensive research over the past ten years	Little empirical information

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Appendix 5

Summary of Factors Influencing Adoption of Soil Conservation Practices

Individual characteristics of farmers (limited utility for predicting adoption)
- Educational experiences
- Farming experiences
- Age
- Level of awareness of problem
- Access to information
- Exposure to information

Farm structure factors (best predictors of adoption)
- Gross farm income
- Acres farmed
- Acres owned
- Acres rented
- Access to farm technologies
- Debt to equity ratio
- Past investments in technologies
- Farm tenure

Psychosocial factors (some utility for predicting adoption)
- Perceived profitability of conservation practices
- Stewardship orientations
- Attitudes toward government involvement in agriculture
- Attitudes toward efficiency in decision-making
- Perceptions of relevance of conservation practices
- Perceptions of soil erosion as a problem
- Commitment to environmentalism

Institutional constraint factors (potential predictors of adoption)
- Government farm programs
- Federal conservation programs
- National economic conditions
- Global economic conditions
- Competitive nature of agricultural system

LOCAL AGRICULTURAL INFORMATION AND ASSISTANCE NETWORKS RELATIVE TO GROUND WATER PROTECTION

by

Peter J. Nowak
Associate Professor of Rural Sociology
University of Wisconsin
Madison, WI

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LOCAL AGRICULTURAL INFORMATION AND ASSISTANCE NETWORKS RELATIVE TO GROUND WATER PROTECTION

Peter J. Nowak, Associate Professor of Rural Sociology
University of Wisconsin-Madison

Abstract

This paper examines the role of local information and assistance networks in addressing ground water contamination from agricultural sources. The emphasis is on farmer to farmer referral networks. Three factors determine whether agricultural practices will contaminate ground water: (1) the characteristics of the agrichemical such as its persistence, water solubility, and toxicity; (2) the soil and hydrologic features of the site where the agrichemical is applied; and (3) the application methods and production practices of the land user who applies the agricultural. It is hypothesized that the third factor, especially mismanagement of agrichemicals, are a major source of the contamination problem.

Agricultural decision making is briefly examined. It is summarized by noting that the agricultural decision is not a static event, but is an ongoing, dynamic process. The role of information and assistance in the technology transfer process is discussed. This is a complex process in that different types of farmers rely on different types of information and assistance at different stages of the decision process. The role of information and assistance in this process is to reduce risk and uncertainty.

Existing local information and assistance networks are then briefly examined. This is followed by a secondary analysis of data that addresses effectiveness of these networks. Assessment was in terms of three dimensions: (1) ability to define and specify local problems; (2) establishing the economic and agronomic viability of alternative practices; and (3) providing information and assistance in a format that is accessible and relevant to local land users. A national survey of USDA personnel was used to assess the first two dimensions while a research and education project in Iowa was used to assess the third dimension.

It is concluded that existing information and assistance networks falls far short of what is expected or needed to realistically address current ground water problems. Farmer to farmer referral networks are offered as one technique that might be used to address this deficiency. A recommendation for supporting these networks is offered. Recommendations are also made for a uniform national assessment of the ground water problem with the county as the unit of analysis; a greater role for farmers in research and dissemination programs; and, improved coordination between the private and public sector relative to local information and assistance networks.

LOCAL AGRICULTURAL INFORMATION AND ASSISTANCE NETWORKS RELATIVE TO GROUND WATER PROTECTION

Abstract i

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LOCAL AGRICULTURAL INFORMATION AND ASSISTANCE NETWORKS RELATIVE TO GROUND WATER PROTECTION

Sources of Agrichemical Contamination of Groundwater

There are three major factors that determine whether agrichemicals will contaminate the ground water (Fleming, 1987). The first factor is the characteristics of the agrichemical such as its persistence, water solubility, and toxicity. Toxicity is important if the focus is on ground water *contamination* as opposed to *movement* of a substance to ground water. The second factor is associated with the soil and hydrologic features of the site where the agrichemical is applied. These features can be used to specify the susceptibility of certain sites to ground water contamination. The third factor are the application methods and production practices of the land user who applies the agrichemical.

(Figure 1 about here)

Although much of the scientific and legal attention has been focused on the first two of these factors, the third factor is also important. The land user's decision on what crops will be grown, where they will be produced on the land controlled by the farm operation, assessment of what chemicals are needed to grow the selected crop, the timing of the agrichemical application in the production process, accuracy of the application method, and the handling, storage and disposal of waste agrichemicals and containers are all directly related to the potential for agrichemical ground water contamination. Mismanagement of any of these processes can result in ground water contamination.

A number of the highly mobile, persistent, and toxic chemicals have already been banned from U.S. agriculture (Fleming, 1987). Further, the majority of relevant soil and hydrological features related to infiltration are largely fixed or static across a crop cycle. At least most of those that can be significantly influenced by the land user. Consequently, viable political solutions to this problem need to be built around the third factor --- variation in ground water contamination associated with the agrichemical decisions of the land user.

A fundamental hypothesis underlying this paper is that there is significant mismanagement of agrichemicals. Further, even though there may be little research on the nature and extent of this mismanagement, it is hypothesized that mismanagement is one of the major causes of ground water contamination from agrichemicals. However, it is not asserted that teaching proper management to all land users will "solve" this problem even if that were possible. This strategy would not address the first two factors listed above, nor does it account for climatic and technological-failure causes of ground water contamination. Nonetheless, reducing mismanagement of agricultural chemicals may be the most cost-effective and politically acceptable strategy available. At issue are the different mechanisms for addressing mismanagement. A number of different techniques are available associated with the processes of knowledge generation and dissemination. This paper will focus on only one of these techniques --- the role of farmer to farmer information and assistance networks as one method of addressing the mismanagement of agrichemicals.

Decision Making Regarding Use of Agrichemicals

Agrichemicals often account for a major share of farm production costs (Goldstein and Young, 1987). Consequently, the decision process surrounding purchase and use of these products needs careful examination. There have been a number of extensive studies on agricultural decision making (Rogers, 1983; Lionberger and Gwin, 1982). Decisions related to the adoption of agricultural innovations have been explained by four groups of factors: (1) the ecological context into which the agricultural innovation must fit; (2) the institutional context which may hinder or facilitate the adoption of certain innovations; (3) the nature.of the support and delivery system surrounding the innovation within different settings; and (4) the nature of the farm firm including the characteristics of the decision makers in the operation. The explanatory power of these four factors varies with the nature of the agricultural innovation (Nowak, 1987).

The agricultural decision process have been found to be related to the farmer's capability to evaluate constraints, resources, and opportunities surrounding the farm operation (Bartlett, 1980; Bennett, 1981). "Farmers proceed through the agricultural cycle as master players proceed through a chess game, using an extensive body of knowledge to define potential problems and alternative solutions at each point in the cycle" (Gladwin and Murtaugh, 1980:118). Three generalizations summarize much of this decision making research. First, the agricultural decision is not a static event, but is an ongoing, dynamic process (Bohlen, 1964). Second, assistance and access to information are important influences for the course and outcome of this process (Rogers, 1983). Third, different farmers rely on different sources and types of information at the different stages of this decision process (Beal and Bohlen, 1967).

Experience and indigenous knowledge systems are often a major influence in this decision process (Bartlett, 1980). It is important to recognize that information and assistance can be experiential as well as garnered from informal sources. Information and assistance does not just flow from the "top" (private and public research and education organizations) to the farmer at the "bottom." A consistent research finding is that individuals are important both as sources and evaluators of information (Lionberger, 1960:8).

> "Regardless of practice, or place, or person, adoption decisions almost always involve other individuals as information sources. They may provide initial knowledge of a practice, definite advice as to the course of action to be taken, or reinforcement of decision already made. They may be specialists or outsiders, **but they are more likely to be fellow farmers personally known and trusted.**" (Emphasis added)

Information and assistance regarding the use of agrichemicals come from a variety of sources. In general, information on new agrichemicals largely comes from private sources by means of the farm media and supply dealers. These dissemination mechanisms introduce information about the new agrichemical into the agricultural system. Public research and education organizations then assume their major responsibilities in this area. As the agrichemical becomes more widely diffused, these organizations conduct extensive efficacy studies and develop management guidelines. Finally, conventional wisdom (e.g., 1.3 pounds of nitrogen for every bushel of corn per acre in the Midwest), past experience, and the experiences and advice of other farmers play a major role.

Two major points are being summarized in this brief discussion. First, there are multiple sources of information and assistance available within the farm community. It is not, as commonly perceived, a "direct pipeline" where it is just a matter of coming up with the right information to feed into this process. This fact was summarized in a conversation with a county extension agent reported by Dillman (1985:21).

> "However, he also noted that there was much more to making a decision than simply to having the information. The important act was not the securing of information from a particular place, it was the interaction that interpreted the information in a local context. He concluded: 'if solving problems was only a matter of applying the same information to all problems everywhere, the movie projector would have made us obsolete.'"

Further, these sources of information are not necessarily consistent with each other, and are often contradictory.

Second, although the variability among farmers in terms of which sources they use and trust has decreased over the last few decades, significant variation remains. Different farmers use and depend on different types of information and assistance sources. This is in addition to the long standing fact that farmers use different sources and types of information for different stages of the decision process. One source or form of information and assistance will not work for all farmers. Nor will a source of information and assistance that is accepted for one technology necessarily remain the same for other agricultural practices.

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The Role of Information and Assistance

As noted above, decision making is an incremental and recursive process. If the farmer is to adopt a new practice or technique, then this implies behavioral change. Changing behavior is a complex process involving knowledge, attitudes, and intentions (Ajzen and Fishbein, 1980). Simply stated, the role of information and assistance is to develop a knowledge base from which attitudes and behavioral intentions can be formed or changed. The absence of this knowledge, or the presence of contradictory knowledge results in either a lack of motivation for change or in uncertainty. Uncertainty is often defined as a situation characterized by the lack of information. Uncertainty results in and is equated with risk. Two general strategies have been employed in the area of resource management to reduce this risk. A common strategy is to subsidize or pay the land user to take a risk associated with adopting a new practice. This strategy has been employed with many traditional conservation practices, and in more recent times with reduced tillage systems. A second strategy is to reduce the risk by supplying the information that minimizes the uncertainty surrounding a new practice or technology. This later strategy has received less emphasis in both the research literature and program design. Considering that both proper management or reducing agrichemical inputs are associated with increased managerial sophistication suggests that this second strategy may be most effective relative to reducing the potential for ground water contamination.

In this context the major role of information and assistance is to minimize the risk and transition costs associated with reducing agrichemical use, or changing or improving agrichemical management (Dabbert and Madden, 1986). The more complex the technology or management strategy, and the greater the difference of this new technique when compared to the traditional practice, the greater the risk and transition cost to the land user (Wake et al., 1988). The role of information and assistance is to reduce this risk and transition cost to a point where the land user is willing to make behavioral changes. This research literature suggests a number of critical questions to be answered:

1. To what extent are land users currently being supplied the necessary information and assistance to reduce agrichemical use, or improve or change current agrichemical management?
2. To what extent do current knowledge generation and dissemination mechanisms recognize the fact that different farmers will require different types and sources of information at different stages of the decision process?
3. What is the current and potential role of farmer to farmer information and assistance networks in this process of knowledge generation and dissemination?

The Nature and Scope of Delivery Networks

Supplying farmers with information and assistance has been a major feature of the United States agricultural system since the middle of the last century. Extensive research, education, and outreach (extension) organizations have been built to meet the information and assistance needs of farmers (Chartrand, 1982). As agriculture has increased in sophistication, complexity, and diversity, these organizations have also changed (Schuh, 1986; McDowell, 1988). Both formal and informal local information and assistance networks have emerged (see Figure 2).

(Figure 2 about here)

The core of public agricultural information and assistance networks are the land grant universities, agricultural experiment stations, and the state and federal extension service. Related network components would include the National Weather Service, USDA Crop Reporting Services, and other USDA agencies. One would also include state departments of agriculture, local libraries, schools (FFA, VoAg), and colleges in this category. All these organizations play varying roles in making different forms of information and assistance available to the farmer.

The private agricultural industry has also developed an extensive information and education assistance network. Local dealers and suppliers of farm products and services play a major role in shaping farmer decisions regarding farm inputs. Many farmers depend on recommendations of local suppliers of pesticides and nutrients regarding the type and application rate. These recommendations are often coupled with custom application by these private businesses.

Other formal sources of information and assistance include farmer to farmer referral networks and private nonprofit groups. Informal groups of farmers have emerged in response to the issue of finding viable methods of reducing agrichemical inputs. What is known about these groups is that they can have up to three functions. First, they engage in on-farm experimentation of different reduction techniques and disseminate this information within their network; second, they bring in or contact external sources of information and assistance to help network members; and third, they use different formats (newsletters, demonstrations, meetings, phone calls) to share information among network members.

This is a very cursory and general overview of the nature of the information and assistance network in agriculture. There are a number of detailed studies of this subject, especially the public land grant system, that are beyond the scope of this paper (Busch and Lacy, 1986; Feller et al., 1983, 1984; OTA, 1981; Parrlberg, 1981; Rutan, 1983; Warmer and Christenson, 1984).

CURRENT STATUS OF LOCAL DELIVERY NETWORKS

Two points have been established; that information and assistance is a critical input to decisions regarding agrichemical management, and that there is an extensive delivery network currently in place within the agricultural community. The next issue to be addressed is the status of this existing delivery network relative to meeting the information and assistance needs of land users. If a policy option based on local information and assistance is to be designed, then an analysis of the adequacy of this network is needed.

Three dimensions of this delivery network need to be assessed. First, the extent to which the problem of agrichemical contamination of ground water is being defined and specified to land users. It makes little sense to expect land users to seek alternative practices until they first recognize a problem with existing techniques. This problem can be defined in terms of either the health risks associated with contaminated ground water, or with the economic losses associated with wasted agrichemicals reaching the ground water.

The second dimension is associated with the information and assistance being provided on alternatives to existing practices. Farmers need site specific economic and agronomic facts on these alternatives as part of the adoption decision. It is unrealistic to expect farmers to adopt alternative practices based on stewardship themes or vaguely defined health risks. Although these messages may motivate farmers to seek alternatives, there is low probability of adoption unless they can obtain adequate economic and agronomic information about suggested remedial practices. Supplying this information should be a function of these local assistance networks. It needs to be emphasized that the supplying of this information and assistance does not necessarily mean from researchers, extension professionals, or agency personnel to farmers. The whole concept of farmer to farmer referral networks implies that farmers can also be a source of this information and assistance. Both to fellow farmers and to researchers, extension professionals, and agency personnel.

The third dimension is the format of this information and assistance. Problem definition and economic or agronomic facts must be presented in an accessible and usable format for the farmer. That is, the right type of information in the appropriate format has to be made available to the farmer at the stage of the decision process when that information is relevant.

The information context surrounding farmers is complex and dense. Few farmers have available time or resources to seek out information and assistance that may or may not be relevant. Both time and resources (costs) are involved with this search process. Further, as noted earlier, different farmers use different information sources at different stages of the adoption process. Consequently, it is important that information and assistance be flexible so as to provide farmers with a format that is accessible and relevant.

Definition and Specification of the Problem

A number of research generalizations have been developed in the area of resource conservation that may apply to this topic. Research has found a "proximity effect" working among farmers relative to the perceived degree of a resource problem (Nowak, 1984). The farther away from the farm operation, the greater the farmer's perception of the extent of the problem. As one gets closer to the farm operation, the extent of the problem decreases proportionately. This implies that a critical component of information and assistance needs to be the ability to provide site specific problem definition. That is, to "internalize" what has been treated as an externality in farm production. A related research generalization has been the finding that farmers underestimate their resource problems while overestimating their conservation behavior. Information and assistance supplied to farmers must go beyond specifying a problem with a local area. It must also be able to specify the farm contribution (cause - effect relationships) to that problem. Farmers do not need generalities or slogans. They need site-specific facts.

There is not a comprehensive, national assessment of agrichemical contamination of ground water. Estimates and local assessments, however, do exist for some states (Lee and Nielson, 1987). In large part, however, local information and assistance networks cannot address either definition or specification of ground water problems. Instead, most representatives of local delivery networks are forced to deal in generalities if they address the situation at all. There has been no national assessment of local network personnel regarding the quantity and quality of information and assistance available to them for working with farmers. Nor has there been a comprehensive effort to assess the quality and quantity of information available in those areas where ground water contamination from agrichemicals has been established. Overall, little is known on a national level regarding the capability of local assistance networks to define and specify the problem.

A closely related issue is the extent to which representatives of these local delivery networks believe there is a problem. This belief is important as local network personnel would be reluctant to commit limited time and resources unless they first acknowledged a problem. Their involvement, like the farmers, is dependent on first recognizing a problem which needs attention.

The Soil and Water Conservation Society conducted a national survey of USDA county level personnel in 1987 (Nowak and Schnepf, 1987) and again in 1988. Every fifth county employee (office supervisors) for the Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), and Cooperative

Extension Service (CES) were interviewed relative to the conservation programs found in the 1985 Food Security Act. Several questions were added to the 1988 survey related to water quality problems associated with agrichemicals. One question asked respondents to assess the extent of water quality problems in their county. The intent was to obtain an overall assessment of surface and ground water quality by these USDA personnel. The results are presented by USDA production region in Figure 3.

(Figure 3 about here)

Generalization has to be limited because corresponding data on the actual extent of water quality problems at the county level does not exist. However, because of agriculture's major contribution to water quality problems some judgments are possible (Gianessi et al, 1985; Lee and Nielson, 1987; Hallberg, 1986). First, these local network personnel appear to be underestimating the extent of the problem. For example, Lee and Nielson (1987) show a major portion of the Corn Belt and the Lake States as being areas with potential ground water contamination from both pesticides and nitrates. Yet only a quarter (25.0%) of the respondents in the Corn Belt viewed water quality as a severe or serious problem. Less than a fifth (18.2%) gave this issue the same ranking in the Lake States. A similar situation is found in the Delta States where a large area has potential contamination from pesticides. Only 19.8 percent of the USDA respondents viewed the water quality situation as serious or severe. In the Southern Plains, where a large area is susceptible to nitrate contamination, less than a tenth (9.3%) viewed water contamination as severe or serious. Another third (33.9%) only viewed water quality problems as moderate, while the largest response category were the 47.5 percent who viewed it as a slight problem. Similar patterns can be found in other production regions. The general conclusion is that the extent of the water quality problem is being underestimated by these USDA county personnel.

In addition to underestimating the problem, there appears to be some ambiguity among USDA county personnel on the cause of the problem. Respondents were asked about the extent agriculture contributed to local water quality problems. Results are presented in Figure 4. Nationally, only 1.9 percent said agriculture was the sole cause of water quality problems in their area. Another 38 percent said it was a major, but not the sole cause of these problems. The majority of the respondents, 52.2 percent, said agriculture was a minor cause of local water quality problems. Another 5.1 percent said that agriculture did not cause these water quality problems. The remaining 2.9 percent said they did not know agriculture's relative contribution to water quality problems.

(Figure 4 about here)

There was significant variation between the regions relative to perceived contribution of agriculture to water quality problems. The highest level of renunciation came from the Southern Plains and Southeast. There were 78.8 percent and 76.0 percent, respectively, who said agriculture was not a cause or only a minor cause of water quality problems. Respondents in the Northern Plains appear to have a more realistic assessment based on the data from Lee and Nielson (1987). These low population but agricultural dependent areas of the Northern Plains had a significant number (53.6%) reporting agriculture as a major or sole cause of water quality problems. On this same end of the spectrum, a large proportion of USDA respondents saying agriculture was a major or sole cause came in the Lake States and Corn Belt (62.4% and 54.6% respectively).

Again, this data is difficult to interpret without corresponding county level data on agricultural contribution to water quality problems. However, it does illustrate that at least half of the USDA county level personnel in seven of the ten production regions view agriculture as being a minimal contributor (none or minor) to water quality problems. Further, in two of the production regions (Southern Plains and the Southeast) three out of four USDA county personnel viewed agriculture as an insignificant contributor (none or minor) relative to water quality problems. Even when considering the significant variation between agriculture's relative contribution to water quality problems between regions, the data indicate that USDA county staff are underestimating agriculture's contribution to water quality problems. It is highly probable that representatives of these local information and assistance networks are doing little regarding problem specification and definition.

Establishing Economic and Agronomic Viability of Alternatives

Farmers cannot work with generalities. Although general ideas may appear to be useful, they still have to be translated into practical, site-specific facts. In particular, they need information on the agronomic requirements and economic consequences of the practices relative to the specific ecological setting of the farm. Farmers attempt to obtain these facts by one of two general methods. First, they may take a general idea they likely obtained from a media source and then experiment on a small-scale basis on their own operation. The intent is to adapt the practice to fit soil, climate, planning objectives, pest cycles, machinery, labor, and management skills available. This first method is timely and is prone to failure. Moreover, the ability to risk the resources involved in this trial and error process varies greatly among farmers. Many farmers cannot afford the risk associated with this method and must stay with traditional, proven practices.

The second method is where an information and assistance network provides this locally relevant data. The most common method of this happening is when a farmer copies the behavior of a neighboring farmer. This method accounts for the spatial diffusion pattern found in the diffusion of a new agricultural innovation (Brown, 1981). Local demonstrations or on-farm assistance could also provide this type of information. This, of course, is one of the major functions of the public and private information and assistance network discussed earlier.

As part of the Soil and Water Conservation Society survey discussed earlier, representatives of this public information and assistance network were asked about farmers interest in sustainable agriculture. Responses by USDA agency are presented in Figure 5.

(Figure 5 about here)

Overall, 6.1 percent said there was no interest among farmers, 32.3 percent said there was a little interest, 39.2 percent said there was some interest, 18.1 percent said there was moderate interest,

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and 4.2 percent said there was high interest among farmers. There was variation between the agencies relative to the expressed interest of their constituents relative to this topic. Extension agents were more likely to perceive higher levels of interest, while ASCS respondents reported the lowest level of interest. Respondents from the SCS fell in between these other two USDA agencies.

Perceived level of interest in sustainable agriculture was also analyzed by production region as presented in Figure 6. The highest level of interest is in the Mountain region and the Delta States. Nine percent of the respondents in the Delta States said there was a high level of interest, while 7.7 percent reported this level of interest in the Mountain region. They were followed by the Southern Plains and the Lake States with 5.3 percent and 5.1 percent, respectively. Only 0.7 percent reported a high level of interest in the Northern Plains. A different ranking emerges when combining "high" and "moderate" levels of expressed interest. The Southeast had 29.5 percent expressing one of these upper levels of interest. This was followed by the Mountain region where 27.9 percent had high or moderate levels of interest. On the other end of this distribution, there were 45.6 percent in the Southern Plains who said farmers had little or no interest in sustainable agriculture. The Northern Plains and Delta States also had 43 percent and 42 percent, respectively, in these little or no interest categories.

(Figure 6 about here)

If one equates interest in sustainable agriculture with one of the techniques that may reduce the potential for contamination of ground water from agrichemicals, then, in general, USDA respondents see little interest in this topic. On average, only one out of every five respondents (22.3%) said there was moderate or high interest. The majority (77.7%) said there was "none," "little," or only "some" interest in this topic. The important implication of this finding is tied to the extent these local agency representatives respond to local demands. Extension agents are supposedly the most responsive to local demands. The SCS and ASCS are more of the line agency who respond to programs developed at higher levels. If local demand on this topic is perceived as weak, then few if any resources will be dedicated to generating locally relevant information and assistance.

One conclusion from this data is that farmers are receiving little information and assistance from these USDA agencies relative to the economic and agronomic dimensions associated with agrichemical management, especially as related to reduced reliance on agrichemicals. Generalities may be available, but agency representatives perceive little demand for site-specific information. If the farmer is seeking relevant economic and agronomic information, then in most cases the farmer must turn to private sources or to rely on the trial and error method discussed earlier. This was confirmed in a study of the Practical Farmers of Iowa, an example of a farmer to farmer assistance network, by Mala and Deibert (1988:8).

> "The need for basic information about sustainable practices and for research information was met through personal contacts, trial and error, and alternative agriculture publications. Rodale Publications was the

> most often mentioned source of publications. Little help was received from government research, university research, Extension Service, or radio farm shows."

Further evidence of this lack of information on the economic and agronomic details associated with agrichemical management was found in an ongoing study on Wisconsin. Approximately 300 farmers were identified as attempting to reduce agrichemical inputs. Farmers were asked about major obstacles at the beginning of the transition process and where they are now in the transition. Respondents were given a list of potential problems including obtaining adequate information, yield losses, reductions in net income, labor unavailability, and the lack of necessary machinery. The lack of valid and reliable information was reported as the largest obstacle at both the beginning and at their current stage in the transition process.

Format of Available Information and Assistance

From a fiscal and administrative perspective it is impossible to provide all farmers with site-specific information and assistance that is compatible to their needs. Consequently it is unrealistic to expect formal sources of information and assistance to provide this detailed knowledge on a wide scale basis. Other sources, such as farmer to farmer networks, need to be considered. Yet support for this possibility is based on the extent that current information sources are capable of generating this information and assistance in a format compatible to local farmers.

Administrators of public research and education organizations and private business seek what they perceive to be the most effective and efficient method of providing information and assistance. However, what may be most cost efficient from the provider's perspective may not be the most economically or agronomically effective from the farmer's viewpoint. There is also the equity consideration of just which farmers are receiving information and assistance in a format compatible to their needs.

The Soil and Water Conservation Society survey did not address format of information and assistance. However, a survey in the Big Springs Basin in northeastern Iowa does provide some insight. This area has serious ground water contamination problems from agricultural production. Iowa State University, working with the Iowa Geological Survey and other organizations conducted a large research project in this area during the mid-1980's. One small part of this research involved farmer interviews regarding the format and reliability of information and assistance sources. One question asked farmers to check the sources of information they had used in the past two years regarding the relationship between farming practices and ground water contamination. Results are presented in Figure 7. County Extension and a Big Springs Basin newsletter were identified as the sources most often used by farmers. The mass media (radio, newspapers, farm magazines) and ISU experts were also identified as an information source by at least half of the respondents. Private businesses were identified by few farmers as providing this type of information. Neighbors and friends were also a minor source of this type of information. It is important to understand overall uses of information sources versus when they are used in the decision process. The mass media

(Figure 7 about here)

and newsletters are good sources to create general awareness of the problem and the types of alternatives available. They cannot, however, provide the site specific information needed for the actual adoption decision.

The reliability of these information sources are presented in Figure 8. Farmers were asked to rank the reliability of these sources on five point scale (1=very unreliable; 5=very reliable).

(Figure 8 about here)

The non-response (NR) values in Figure 8 refers to the percentage of farmers who did not provide a reliability ranking because they had not used or were unfamiliar with that particular source. The County Extension and the local newsletter received the highest reliability scores. They were closely followed by the other public agencies. Private industry and neighbors and friends received the lowest reliability scores. In addition to reliability, the non-response data in Figure 8 also points out that many potential sources are not being considered or used as information providers.

Two items need to be kept in mind when interpreting Figures 7 and 8. First, this area of Iowa had received a lot of attention by public agencies and the mass media in specifying the problem, and in identifying the sources of these problems. The Big Springs Basin area cannot be considered representative of areas where ground water contamination from agricultural sources is found. In fact, the newsletter receiving such a high evaluation was developed as part of this project. Second, past adoption research (Rogers, 1983) supports the finding that neighbors and friends would not be a major supplier of information in the definition of a problem, especially one related to health or environmental concerns. Farmers are largely dependent on private and public sources for information and assistance relating to the technical dimensions of problem definition. There is a second reason why other farmers scored so low in the above research. Other farmers, neighbors and friends serve as an evaluator or legitimizer of information. The credibility given to items of information or potential assistance is partially based on the evaluation by these neighbors and friends. If the above research project had asked about an evaluation of alternative practices being promoted by different sources, a very different ranking would be found. Too much research in this area fails to discriminate between general sources of information on a practice or issue versus specific sources of information used in the evaluation of that practice or issue.

These findings confirm earlier observations: no one source of information or assistance is used by all farmers. Instead, farmers within an area use a variety of sources with differing levels of credibility. Further, although not directly tested in this research, the source of information will shift when moving from gathering knowledge on a problem or practice to evaluating the suggested remedial practices. It is also important to note that this knowledge gathering process is still occurring in an area where there are significant ground water problems from agriculture, and where a major research and education project had been developed. In areas where this extensive effort is not underway, problem recognition, knowledge gathering, and practice evaluation processes must be occurring at a much slower rate.

Another critical question regarding local assistance networks concerns the format of the information and assistance. That is, not only is the source important, but the format used by that source is also equally important. Results from the Big Springs Basin Project regarding this dimension are presented in Figure 9. Pamphlets are by far the most used format of information employed in the last two years regarding agriculture and ground water contamination. Almost half of the farmers reported using this format of information. The other three formats all had less than 20 percent of the farmers using them in the last two years. The reliability of all four formats scored approximately the same on the five point scale.

(Figure 9 about here)

These use levels are a sobering reminder of the complexity of the technology transfer process. Even in this area where ground water contamination had been established as a major problem, we find very low levels of use among very traditional formats. This needs to be considered when evaluating the potential effectiveness of new formats such as computer models and the like. If less than one out of five farmers are using formats that have been available across the last half century, then is it realistic to expect widespread audience participation with some of these newer formats? Richardson and Mustian (1988:2) report a similar conclusion from their study of North Carolina farmers.

> "Agricultural producers surveyed generally expressed a strong preference for those information delivery methods that can be classified as traditional Extension methods. When asked to list the five methods most frequently used, producers listed as most important (1) newsletters, (2) meetings, (3) farm visits (agent to farmer), (4)

> telephone calls, and (5) on-farm tests and demonstrations. Newer Extension informational delivery techniques such as teleconferencing, video tapes, audio cassettes, cable television, and home study courses were rated quite low as preferred methods for receiving information."

An advantage of farmer to farmer referral networks is that it does not rely on any one dissemination technique. Instead, it recognizes that learning occurs under multiple situations. Learning "correct" agrichemical management is a process that will depend on multiple formats and sources. Moreover, farmers not only have to learn "what" has to be done, but they also have to learn how to make that "what" operate efficiently within their farm operation. Wake and colleagues (1988) identify three techniques of agricultural learning. Informational learning (learning by information), observational learning (learning by observation), and experiential learning (learning by doing). Informational learning is associated with the more formal sources of information disseminated through the print and electronic media. Farmer to farmer networks would play a minor role in this process. Instead, these networks are designed to take advantage of observational and experiential learning. Network members are encouraged to observe neighboring or network member farms and local demonstration sites. They are also encouraged to experiment on a small scale basis on their own farms, experiential learning. The strength of farmer to farmer referral networks is not in informational learning. Instead it is in the other two forms of learning, and in the process of making practices work better (efficiency considerations) under local agroecological conditions.

OPTIONS FOR IMPROVING NETWORK EFFECTIVENESS

This brief summary of the literature pointed out a number of areas where local information and assistance networks could be made more effective relative to reducing agrichemical contamination of ground water. However, prior to discussing specific strategies, one overriding concern needs to be expressed. This is the lack of research information on the role, structure and efficacy of these local information and assistance networks. It is noteworthy that none of the data used in this paper directly assessed the nature and effectiveness of these informal local networks. Although early adoption and diffusion of agricultural innovations research in the 1950's identified these as major factors, little has been done since. This level of ignorance is combined with the fact that farmer to farmer assistance networks are emerging in all agricultural areas of the United States regarding sustainable agriculture. This needs to be a priority for USDA research agencies and the land grant universities. A significant effort is currently underway to define the problem, and to generate knowledge on alternative solutions. However, little attention is being given to the efficacy of different dissemination methods. It appears that an overriding assumption is that traditional dissemination methods are effective, and all that is lacking are technological innovations to make these traditional methods more cost effective (e.g., teleconferencing, computerized expert systems, and video). This unrealistic assumption is ignoring a vast amount of literature that has been accumulating on dissemination mechanisms associated with Farming Systems Research (Lightfoot and Barker, 1988), or with what has been called the Farmer First and Last model of knowledge dissemination (Chambers and Jiggins, 1987a, 1987b).

Farmer to Farmer Information and Assistance Networks

Consequently, the first recommendation needs to be both the study and support of these local assistance networks. Many plans and efforts are being developed to accelerate information and assistance through traditional university, extension, and conservation agency networks. Few if any, however, are considering formal support for the development and maintenance of these farmer to farmer information and assistance networks. One alternative, therefore, would be to create a program that would support these farmer networks. This could provide payments to farmers to engage in field experiments regarding better management and possible reduction of agrichemicals. An obligation of these payments would be the participation in a local farmer network where field experiments would be reported. Funds would also be used to support the dissemination of results in multiple formats both within and beyond the local network. Government agencies and private sector organizations role in this process would be one of support rather than leadership. They could supply criteria for valid field experiments, provide technical assistance, assist in producing the results, help establish these networks, and in other roles deemed appropriate by participating farmers. There are several models around which this program could be designed. The Sustainable Agriculture Program managed by the Wisconsin Department of Agriculture, Trade and Consumer Protection; the Minnesota Department of Agriculture's Energy and Sustainable Agriculture On

Farm Demonstration Program; and the Iowa State University Leopold Center's relation to the Practical Farmers of Iowa immediately come to mind. However, none of these examples are able to provide enough incentive to farmers to offset the risk involved with field experiments or to pay for adequate dissemination of the results. The state programs also require the farmer to go through a formal grant application and review process. These formal requirements would limit farmer participation as it may be perceived as "another government program."

This program could be funded by the federal or state government with the intent that as soon as adoption of remedial technologies reached pre-determined levels in targeted areas, or certain parameters associated with problem definition were achieved, the funding would be phased out. One final consideration of such a program would be to establish it only in those areas of the country where the potential contamination of ground water from agriculture has been determined to be high.

Developing Problem Definition and Specification

A better mobilization of existing local information and assistance resources could occur if there was a better specification of the problem. While a significant amount of research is occurring on the relation between agriculture and ground water, little has been dedicated to a uniform, national assessment of vulnerability and contamination levels. The Environmental Protection Agency assessment currently underway may address some of this concern, but it is a timely and costly process when compared to state initiatives (e.g., Wisconsin's sample of 600 farms) that have already attempted to fill this void.

Since it is critical to have a uniform assessment, EPA or congressional action would be needed to specify assessment procedures. This administrative action could specify criteria for selecting sampling sites, sampling methods, and a standard spectrum of compounds for which tests would be conducted. This action would help insure uniformity and comparability of results across time and geographic locations.

Another important component of this assessment procedure would be a specification of the format to be used in disseminating the results. A uniform format would have to be designed that would be understandable to both local information and assistance network personnel and the land user. The unit of analysis of this assessment should be the county as most assistance networks are built around this political unit. Scientifically it may be more valid to assess hydrologic, geologic, or soil units of analysis, but these are often incompatible with local units of government. If correcting the problem is the ultimate objective, then the data has to be collected and organized with dissemination in mind.

A related theme would be to establish procedures so that all agricultural research would assess the contribution of the production technique to ground water contamination in areas where the production technique would be employed. This would help address the situation where production research is often organized and presented as independent from research on the natural resource base. This procedure could be implemented by the agricultural experiment stations.

Design of Appropriate Technology and Dissemination Formats

Many of the references cited earlier discussed the lack of responsiveness by the land grant university and extension to the needs of land users. Many other citations, as well as testimonials, could also be presented. Yet this is unnecessary as the point has been made. Too often research and extension is carried out in response to the priorities established by professional peers and the demands of funding organizations. Design of complex and sophisticated technologies that address agricultural contamination of ground water may be professionally rewarding, but may have little relevance to the typical farm or ranch. The core concept behind appropriate technology reverses this order: an understanding of the needs and capabilities of multiple target audiences serves as the foundation for the design of remedial technologies. Farmer to farmer referral networks are one mechanism that could be used to gain this understanding. More emphasis needs to be placed on this strategy in developing funding priorities for research and extension activities. Further, eligibility for agricultural competitive grants need to be expanded so as to allow assessments of different target audiences relative to the technology transfer processes. Research scientists base their work on a rich classification of the physical setting, but have a tendency to view farmers as a homogeneous group when it comes to dissemination.

Dissemination of research results and tests of appropriate technologies needs to recognize the complexity of the technology transfer process. Too much emphasis is being placed on finding the "technological fix" to agricultural contamination of ground water. Or it is being placed on specifying the problem in great detail and depth while ignoring the actions of the land user whose actions may cause the problem in that situation. This may be the complex computer model that would be accessible to only a few farmers and understood by fewer still; the design of plants and animals through biotechnology that will reduce reliance on agrichemicals; or the use of sophisticated telecommunication devices to which few farmers have access or willingness to use. More emphasis needs to be placed on how to mobilize existing information and education networks in order to address today's problems with today's technologies and management strategies. One method for this to occur would be to develop greater involvement of farmers in the design of research projects and remedial programs. Although some would argue that this is already happening, too often these farmers are not representative of the majority. They are instead selected on the basis of their past cooperation or use of recommendations from the private and public assistance network. Yet the farmer who has not followed past recommendations or is not tied into the existing county extension network also needs to be heard. Farmer to farmer referral networks may be one technique of overcoming the bias often found in formal information and education efforts of only working with the "cooperative, progressive" farmer.

Public Agency and Private Sector Coordination

A critical problem facing local information and assistance networks is that they are composed of both the private and public sector elements. The public sector is there to assist production, protect the resource base, and manage agricultural programs. The private sector is there to assist production through selling products and services. This is a problem in that recommendations from one sector often are contradictory with recommendations from the other. This can be in the use of soil tests in developing nutrient recommendations, identification of what constitutes a "pest" and the appropriate remedial action, or the use of market mechanisms to promote agrichemical use in response to agricultural commodity programs. Local information and assistance will continue to be less than effective until a coordinating mechanism is developed.

This coordination needs to occur on two levels; within and between the sectors. Coordination within the public sector regarding resource management has been found to be deficient (Hoban, 1986; Nielson, 1986). A major factor behind this situation is national legislation that only considers the design of agricultural policy while largely ignoring implementation. A situation has developed where each agency has their programs and constituents while rarely considering that these constituents may be participants in other agency's programs. More attention needs to be given to implementation requirements and inter-agency relations while drafting national legislation. Coordination within the private sector would also be difficult in that these parties are in competition with each other. The industry faces the prospect of either increasing cooperation relative to preventing resource degradation or to be subjected to increasing federal and state regulation. Therefore, more effort has to be placed on finding programs and activities that will increase this cooperation and coordination. Studies need to be conducted on both private and public sources of information and assistance relative to obstacles to cooperation and coordination.

CONCLUSION

Local information and assistance networks can play a meaningful role in the reduction of agrichemical contamination of ground water. This could occur in two ways. First, by decreasing the current mismanagement of agrichemicals through providing locally relevant information and assistance. Second, they could increase the adoption rate of management techniques and technologies that minimize the probability of ground water contamination. This meaningful role, however, is unlikely considering the current assessment of these information and assistance networks.

An overview of the situation found USDA agency personnel unable to define and specify local ground water problems, and lacking basic economic and agronomic facts on remedial technologies and management techniques. In addition, the dissemination literature cited in this paper has found traditional U.S. agricultural outreach efforts largely insensitive to using different sources of information in different formats in order to meet the needs of the largest number of land users. Farmers are viewed only as targets for information and assistance rather than being sources of this knowledge.

Underlying this dismal assessment is the fact that very little substantive research has been conducted on the role, structure, and efficacy of these networks. Much of our current understanding is only suggestive while being based on antidotal information or a few studies of very limited scope. A number of general recommendations were made to address this situation beginning with more research on these networks.

There is no question that agriculture will have to respond to ground water contamination in a meaningful way due to current political and demographic trends. At issue is the form of this response. This response will fall along a regulatory to voluntary continuum, probably being a mixture of both. The underlying theme of this paper is that an effective voluntary approach has to be based on a viable information and assistance network. Yet the viability of the current information and assistance network has been questioned. What remains to be seen is our response to this situation, and whether farmer to farmer information and assistance networks will play a meaningful role in this process.

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FOOTNOTES

1. The survey population was drawn from the county offices of SCS, ASCS, and CES. From lists provided by each agency we randomly selected a 20 percent sample of the counties in each state. A questionnaire was then mailed to this group during March and April of 1988. This was a twenty-five question instrument including two open-ended questions at the end. A post card followed approximately two weeks later reminding them to return the completed questionnaire. Of the 1,770 questionnaires sent out, 1,267 were returned with usable information for an overall response rate of 72 percent. Individual agency response rates varied between 80 percent in ASCS (485 of 609 were returned) to 61 percent in CES (375 of 613 were returned). SCS has a response rate of 74 percent (407 of 548 were returned).

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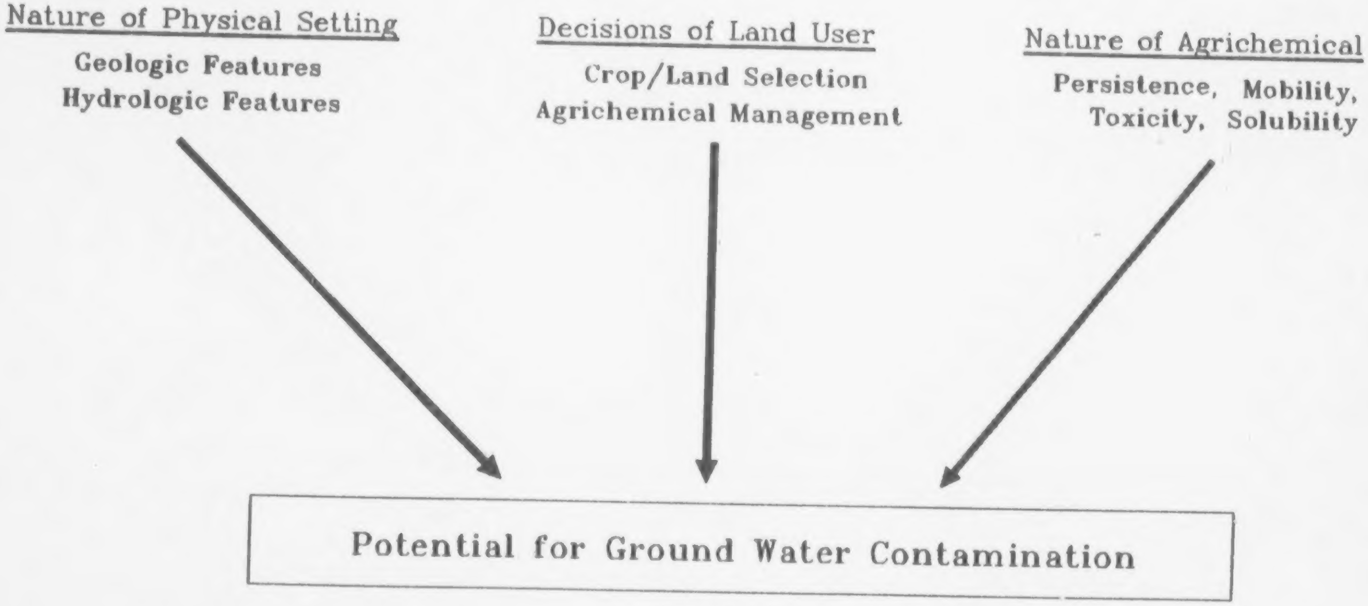
FIGURE 1: FACTORS AFFECTING THE POTENTIAL FOR GROUND WATER CONTAMINATION FROM AGRICHEMICALS



Nature of Physical Setting

Geologic Features
Hydrologic Features

Decisions of Land User

Crop/Land Selection
Agrichemical Management

Nature of Agrichemical

Persistence, Mobility,
Toxicity, Solubility

Potential for Ground Water Contamination

Figure 2: Local Information and Assistance Network Members Relative to Farmers and Agrichemical Management

Members	Nature of Contacts	Role	Interactions
Extension	Local/state/U.S. agency Formal structure/function	Education emphasizing production techniques	Mainly cooperative farmers
SCS	USDA agency Formal structure/function	Technical assistance on erosion control	Mainly farmers with erosion problems
ASCS	USDA agency Formal structure/function	Participation in US farm programs	Farmers participating in farm programs
Crop Consultants	private business Both formal/informal	High management and inputs production	Mainly 'progressive' farmers
Supply Dealers	private business Both formal/informal	Sales and service of production inputs	farmers
Local Media	private business Both formal/informal	Reporting on programs & factors of production	Focus on new ideas
FFA/VoAg	youth education Both formal/informal	basic production theory and practice	Student/parent discussions
Farmers	private business informal	Evaluation, generation & use of production techniques	Other farmers with similar goals & operations

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Figure 3: USDA County Personnel View of Water Quality Problems by USDA Production Region

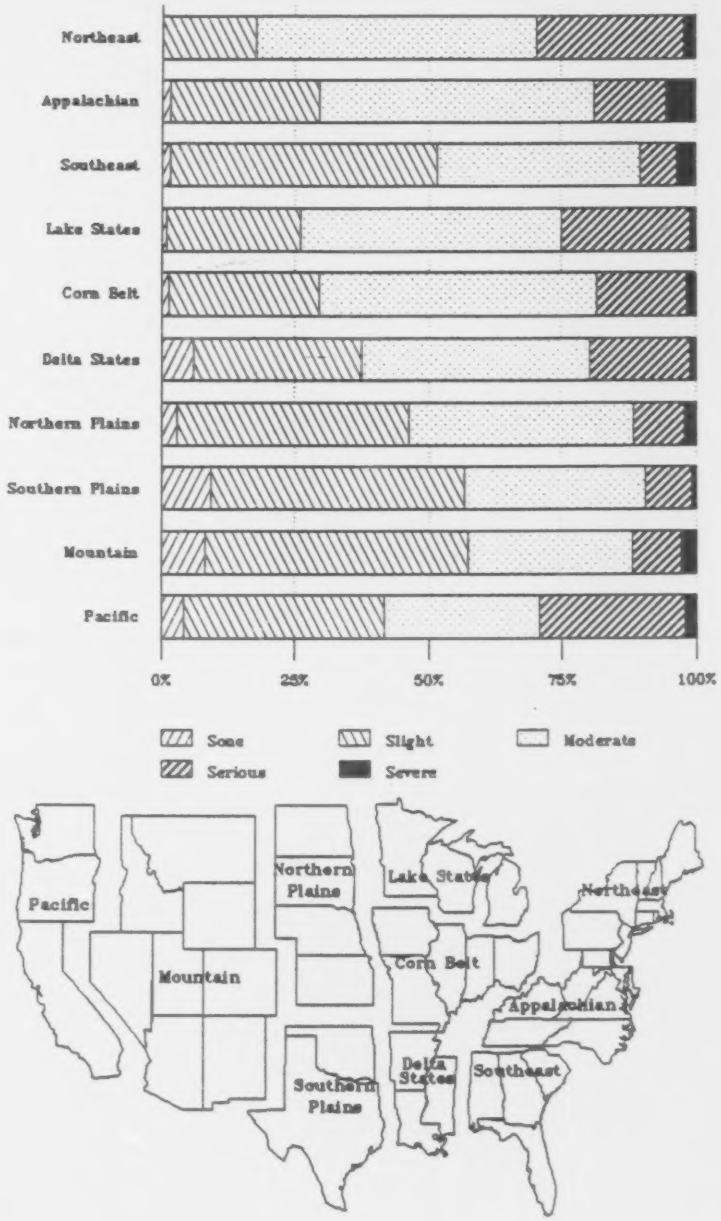

Figure 4: USDA Personnel Perception of Agriculture Causing Water Quality Problems by Production Region

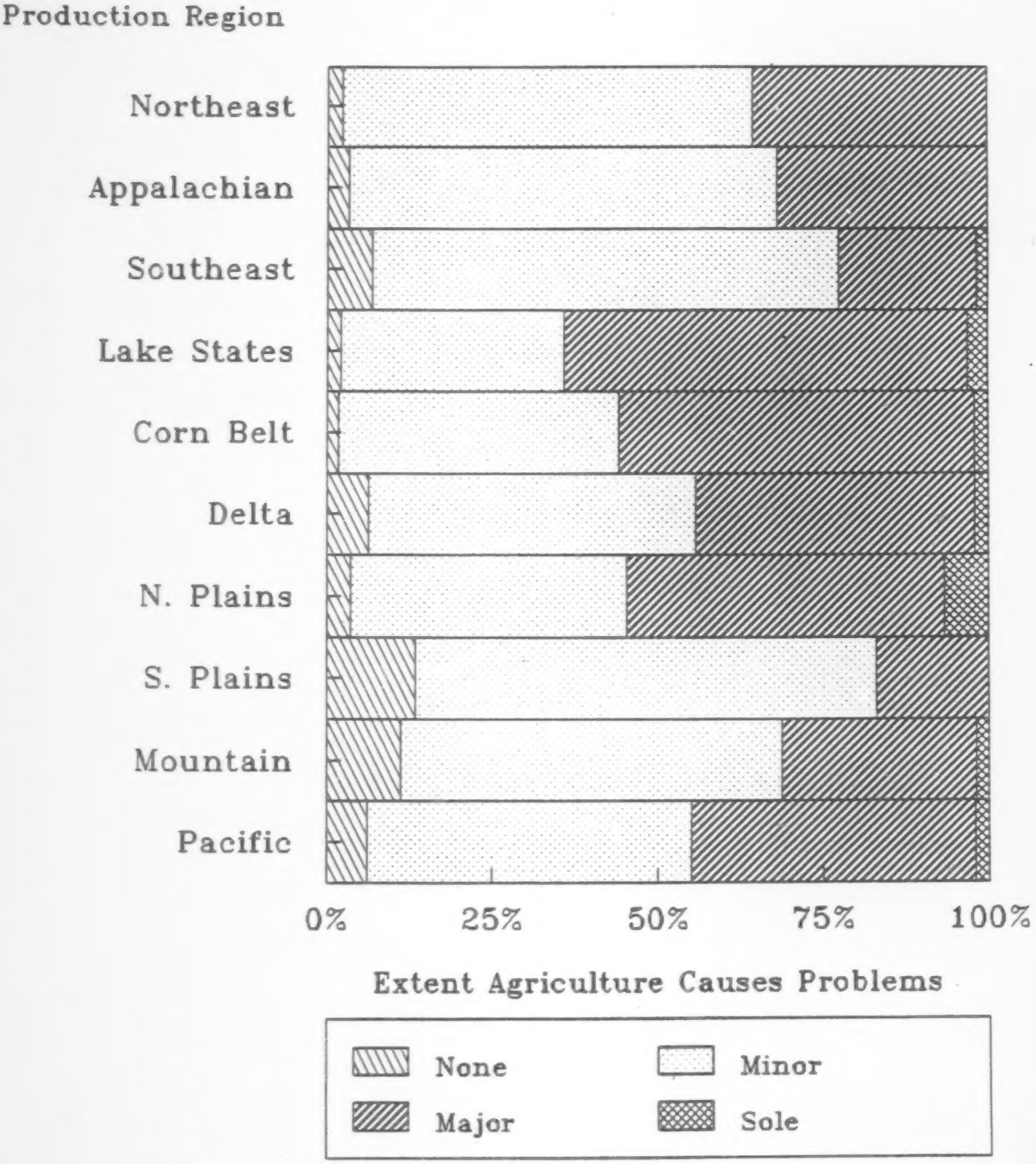

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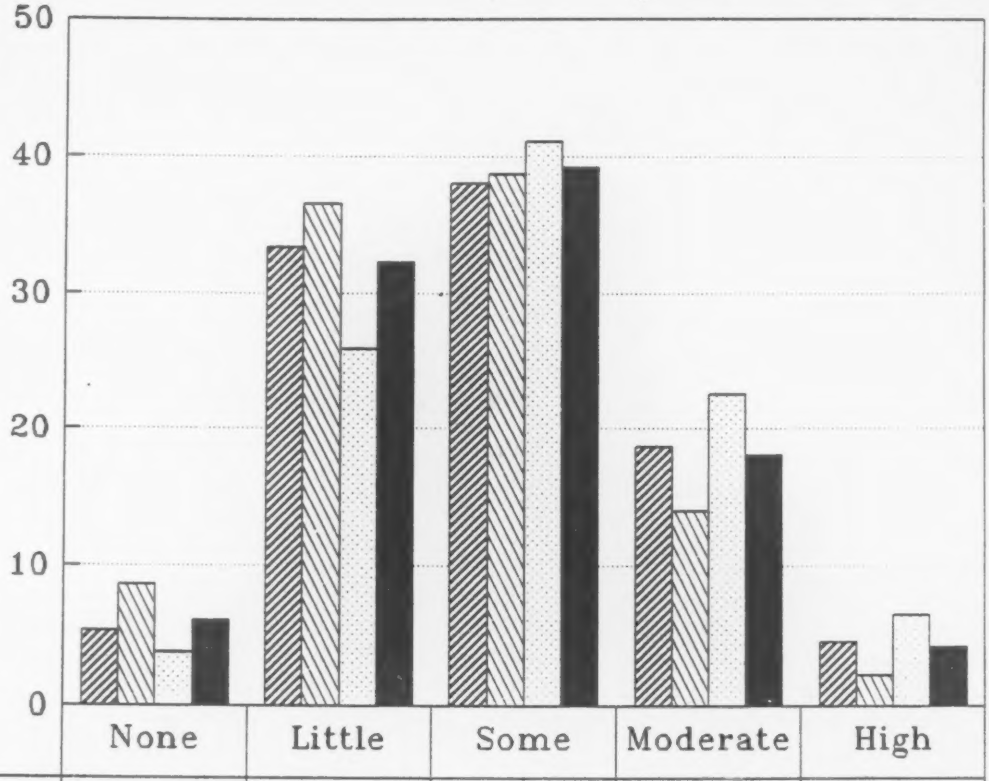
Figure 5:
Farmers Interest In Sustainable Agriculture As Reported By USDA County Personnel



	None	Little	Some	Moderate	High
SCS	5.3	33.4	38	18.7	4.6
ASCS	8.6	36.5	38.7	14	2.2
CES	3.8	25.9	41.1	22.6	6.5
Total	6.1	32.3	39.2	18.1	4.2

Respondents: SCS = 407; ASCS = 485; CES = 375

▨ SCS	▧ ASCS
░ CES	■ Total

Figure 6: Farmer Interest In Sustainable Agriculture Reported By USDA Staff By Production Region

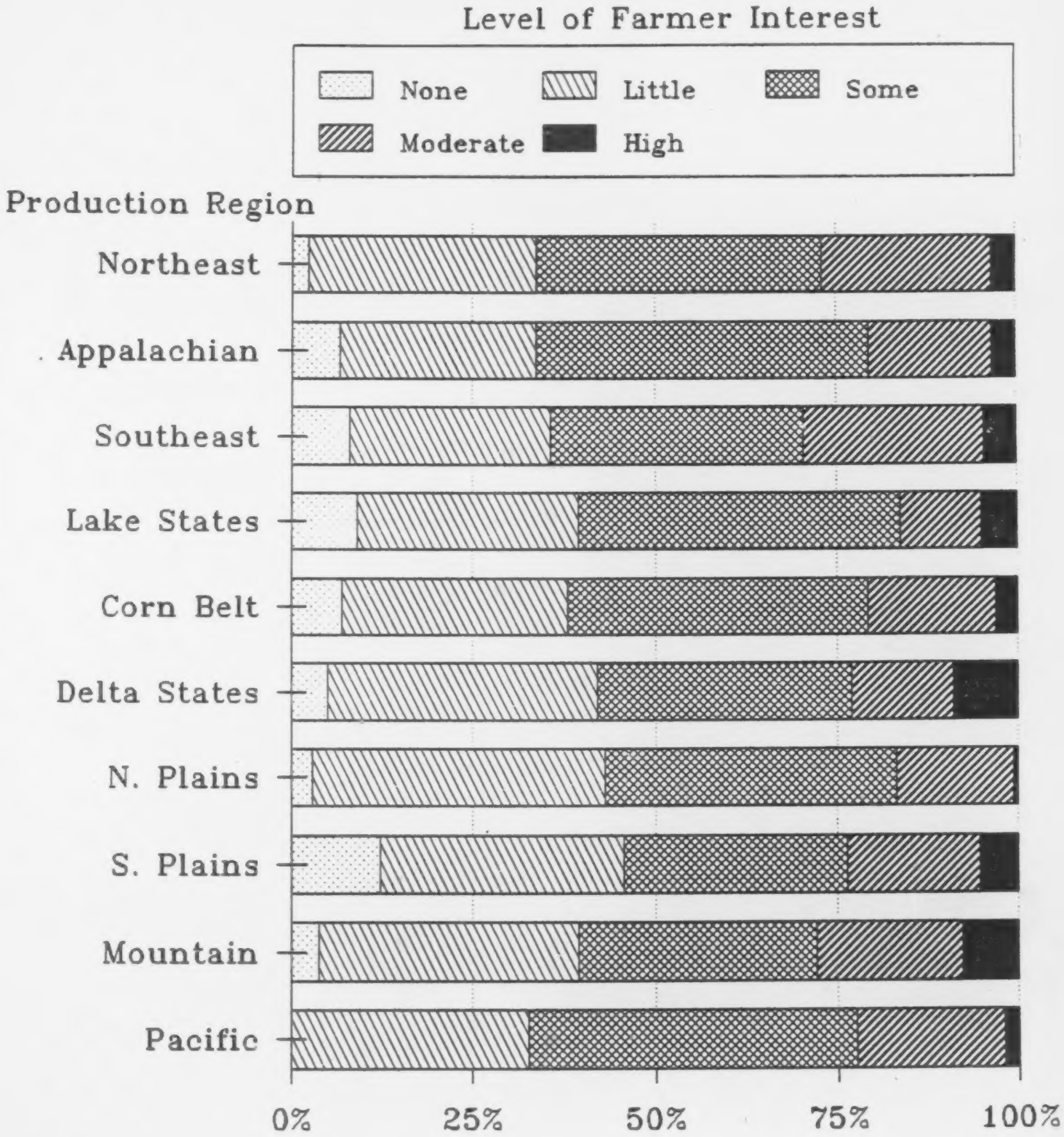
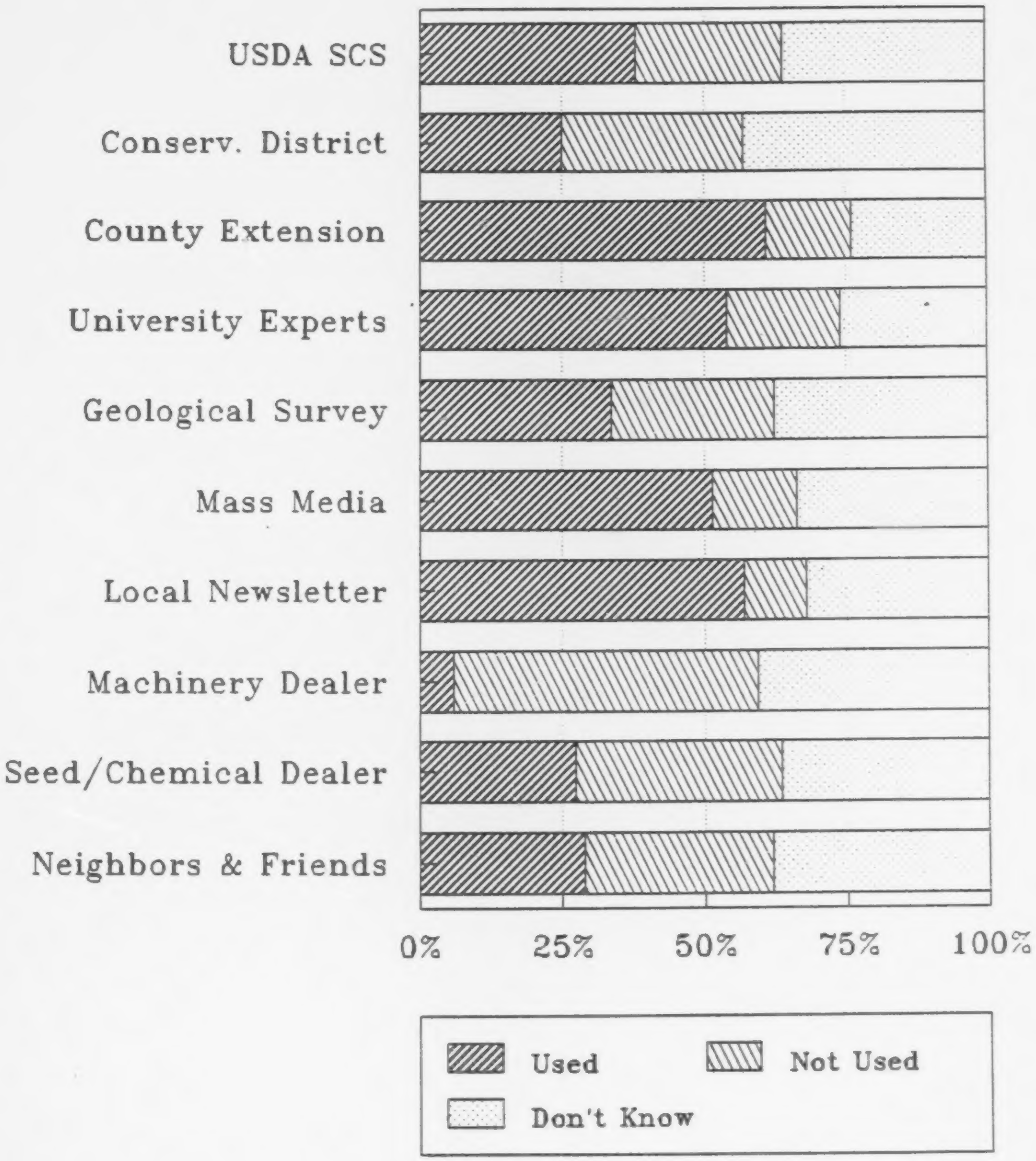
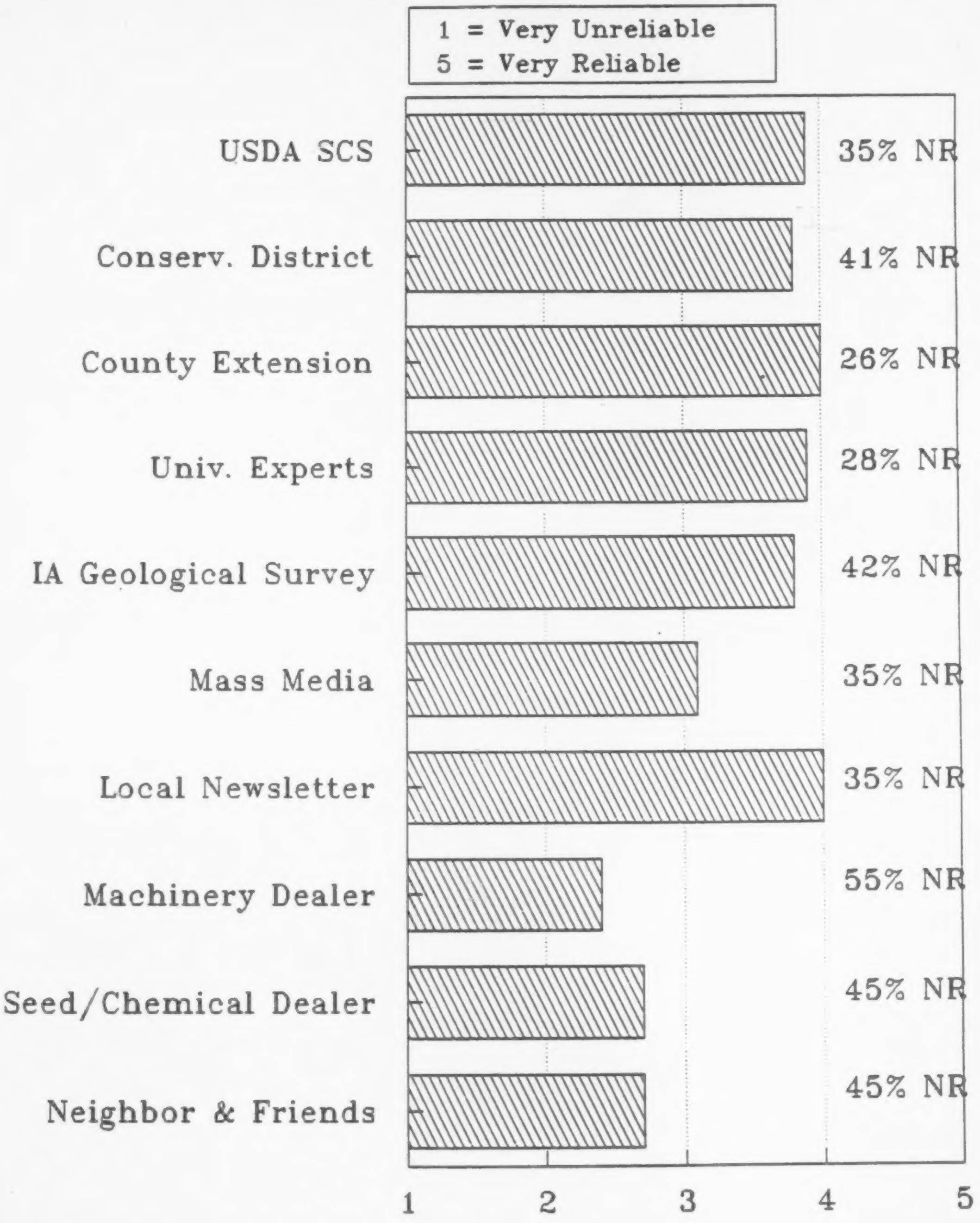


Figure 7: Use of Information Sources in Past Two Years on Farming & Groundwater



Big Springs Basin Project, Iowa, 1984

Figure 8: Reliability of Information Sources on Agriculture/Groundwater



Big Springs Basin Project, Iowa, 1984

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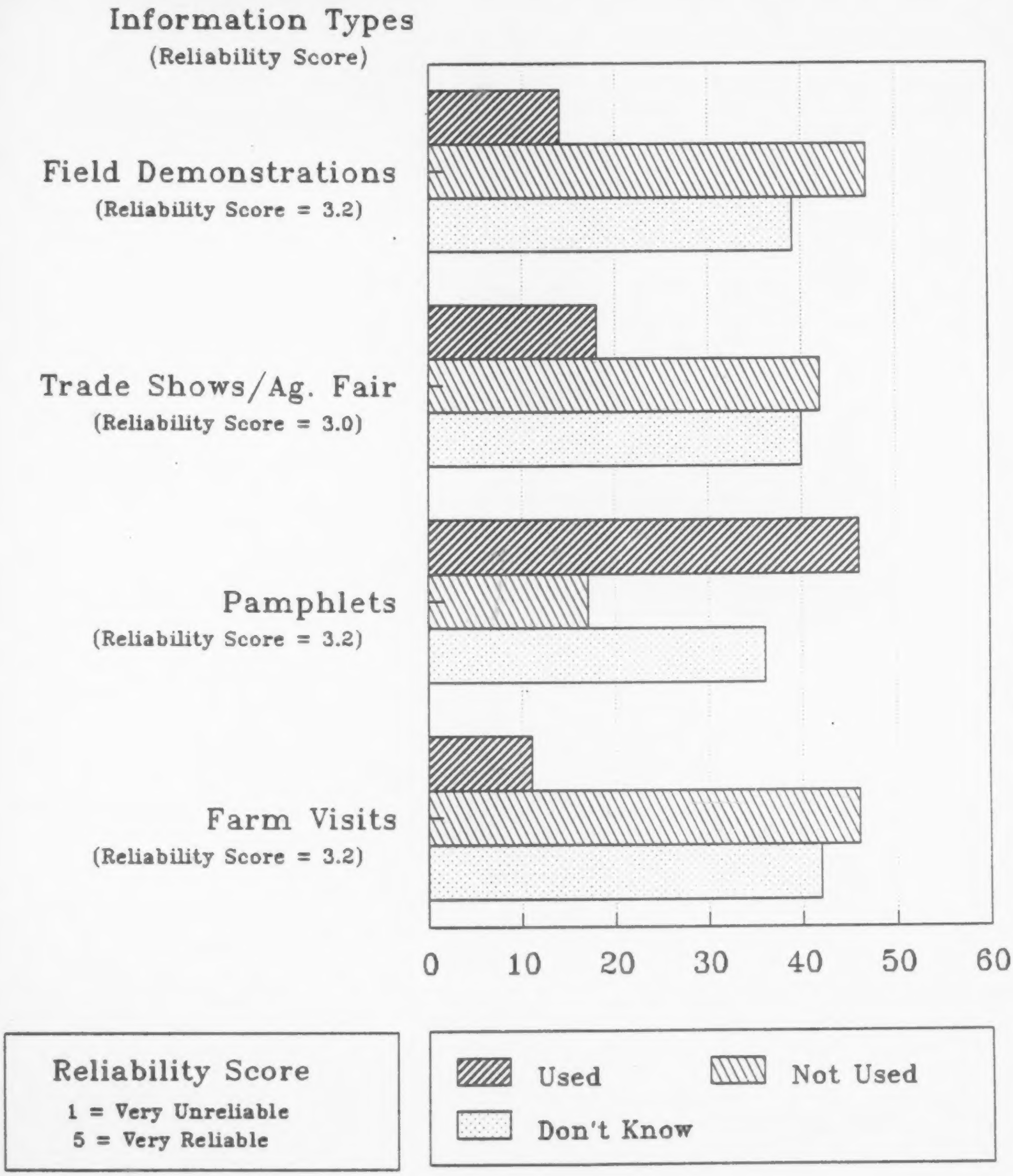
Figure 9: Use of Types & Reliability of Information on Farming & Groundwater



Big Springs Basin Project, Iowa, 1984

EXTENSION EDUCATION FOR AGRICHEMICAL DEALERS ON GROUNDWATER PROTECTION: AN EXTENSION PERSPECTIVE

by

K. A. Kelling
Professor and Extension Soil Scientist
Department of Soil Science
University of Wisconsin
Madison, WI

J. L. Wedberg
Professor and Extension Entomologist
Department of Entomology
University of Wisconsin
Madison, WI

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Author(s) name(s), Contract paper title, prepared for the U.S. Congress, Office of Technology Assessment, *Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemical Contamination of Groundwater* OTA-F-418 (Washington DC: U.S. Government Printing Office, November 1990).

Extension Education for Agrichemical Dealers on Groundwater Protection: An Extension Perspective

K.A. Kelling and J.L. Wedberg[1]

I. Introduction and rationale

The development and use of fertilizer and pesticide practices which recognize the benefits of these materials, but at the same time minimize their impacts on the environment, is becoming one of the major issues facing agriculture and the general public today. Issues such as farm profitability, surface and groundwater resource protection, consumer and food safety, and viability of farms and rural communities have all become increasingly important during the late 1980's. If these concerns are to be faced, there is a substantial need for increased education for farmers, agribusinesses, consumers, and governmental agency personnel on the relationship between agricultural practices and environmental quality (UWEX, 1988). Increased education of agrichemical dealers is critical because this group is intimately involved with the farmer in selecting the materials, rates and actual practices employed. Dealers are present when the product or practice is selected, are consulted on their knowledge of product performance, differences and recommendations, and in many cases actually apply the fertilizer or pesticides to the field.

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[1] Professor and Extension Soil Scientist, Department of Soil Science, and Professor and Extension Entomologist, Department of Entomology, respectively, University of Wisconsin, Madison, Wisconsin 53706.

Agrichemical dealers usually offer a combination of fertilizer and pesticide products and services to their clients, although some companies will only handle one type of product. Most states already recognize these agribusiness people as one of the major audiences served by the agricultural component of Extension; however, in some cases programs for this audience group are incomplete or nonexistent, and in other cases could be improved. Extension programs for agrichemical dealers and consultants are particularly important, because this group has direct input into the farmer's decision as to what practice or chemical will be used and the rate at which it will be applied. They are an integral part of that decision-making process. Almost every survey conducted on agrichemical use shows that, next to past experience, the dealer or independent consultant is the primary source of grower information on fertilizer and pesticide use (Wisconsin Agriculturist 1985; Farmland Industries, 1984; Forrest et al., 1988). Extension is commonly rated as the fourth to eighth most important source of information for growers on these topics, but usually first or second on information credibility. It is also well documented that Extension is often the primary source of the information provided through other outlets such as dealers or trade journals even though this original source is not recognized.

Dealers and consultants also serve as important disseminators of university-generated information. Dealers employ sales people, agronomists and, in some cases, pest scouts. All of these individuals, as well as independent crop consultants provide farmers with information and advice as to the best practice for a given situation. If this message is similar to that being provided by Extension, conflict is avoided and greater credibility for all parties is developed. Extension programs in some states such as Wisconsin have recognized the benefits of cooperation and provided special educational efforts for dealers, including the Annual Wisconsin Fertilizer and Pesticide Conference (Proceedings of the Wisconsin Fertilizer Aglime and Pest Management Conference Vol. 1-28), area dealer meetings, (12 pesticide, 10 fertilizer and 9 seed dealer meetings each year), crop management workshops, IPM (Integrated Pest Management) scout schools, newsletters such as the Wisconsin Pest Manager (UW Agronomy Dept.) and the Crops and Soils Newsletter (UW Soil Science Dept.), and written materials such as the Herbicide Manual, various fertilizer and pest management fact sheets and conference proceedings and popular press articles.

One should not be so naive to think that university information which is passed to the farmer through the dealer is not subject to selection and interpretation by the dealer. Although farmer acceptance of the dealer's recommendation may be increased by aligning the dealer's suggestions with university philosophies or programs, there is little economic incentive on the part of the dealer to recommend a bare-bones, environmentally-oriented fertilizer or pesticide program when the dealer's sole source of income is based on product sales. However, there is an opportunity for both parties to benefit because a common question put to dealers is, "What does the university recommend?". If the dealer can show that his program is comparable to that recommended by the university by using techniques such as university soil test recommendation programs or following university pest management guidelines, then significant credibility is gained. In some states this elevation of dealer credibility is of major importance to farmer clients.

If dealer sales are going to be adversely affected by more environmentally driven recommendation programs, we believe that the current trend of farmers paying for advising services of consultants (independent or dealer-affiliated) will have to continue, and that this source of income may partially offset the income lost from decreased product sales. One indication of the increased demand for consulting services was the creation of CENTROL, an independent consulting branch of the CENEX/Land O'Lakes Regional Cooperative, in 1980. There are currently 15 CENTROL offices in operation in 8 midwest states (R.L. Beck, 1989, personal communicator). The success of this transition to more dealer services for pay will be dependent upon the dealer supplying credible and usable information that the grower can translate into improved profitability or acceptance of the environmental benefits.

II. Extension programs for dealer education on fertilizer and agchemical management

A. Current efforts

Extension education programs for the fertilizer and pesticide industry have existed for many years. Programs and levels of activities vary from state to state, but several types of dealer education efforts appear evident. These include: 1) providing dealers with up-to-date research results on crop production, pesticide and fertilizer management; 2) developing and implementing better predictive and diagnostic tools such as pest scouting, economic thresholds, disease protection modeling, soil testing and plant analysis so that dealers can assist their clients in determining fertilizer or chemical needs; 3) helping train dealer employees

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in basic and advanced soil fertility, fertilizer, safe chemical handling and pest management skills; and 4) integrating environmental programming into existing production-oriented programs so that needed changes in philosophies or approaches can be more smoothly incorporated into practice.

For many issues related to environmental or water quality, dealers already have been made aware of the issue or problem. As indicated by program topics at national conferences, articles in agricultural trade journals and dealer attendance at environmentally related programs, the dealer sensitivity to these concerns and pressures is very high. Furthermore, although a basic conflict may exist between sales generation and public environmental good, this audience group is asking for more help. In some states, early programming efforts have resulted in the development of a strong working relationship and confidence between dealers and Extension that can be built upon. These earlier programming efforts may serve as an excellent springboard for more intensified, future programming as additional resources are made available or redirected.

It has been our observation that Extension programs which are consistently successful with the agrichemical industry contain several similar characteristics. These include presenting information which is basically positive in tenor. Negative programming or emphasizing what should not be done often results in audience rejection. Rephrasing or stating ideas in a positive way significantly improves acceptance. For example, in the last several years the poor condition of the farm economy has resulted in a great deal of Extension programming for farmers on agrichemical use in ways to improve production and economic efficiency. One of our more successful programs clearly emphasized ways to address this problem through trying to save money (Kelling and Schulte, 1985). This was considerably more palatable with both dealers and their farmer clients. The information presented must also be presented in an accurate, straightforward, and understandable way which stresses the benefits of the idea or concept. The information or program must be presented such that the potential confrontational position which can arise among product/sales oriented organizations and research, consumer or other client group organization is minimized. This does not mean that controversial issues or differing opinions should be avoided; in fact, they are often encouraged. However, the method of presentation must be balanced, complete, objective, and unemotional.

Vehicles for this type of programming vary substantially among states; however, below we have listed some which are most common.

1. Many states conduct an annual Fertilizer and Agchemical Conference, often in cooperation with the state's Fertilizer and Agchemical Association. Examples include the Wisconsin Fertilizer, Aglime and Pest Management Conference, the Illinois Fertilizer Conference, the Indiana Plant Food and Agricultural Conference, and the Minnesota Soils, Fertilizer and Agricultural Pesticides Short Course. Topics presented at these one- to three-day programs usually center on current research updates, issues which are timely or "hot" for that season, and those expected to be important in the next season. Regulation and/or law changes affecting the industry and new initiatives are often also included. The educational program is often coordinated by a state specialist with input from an industry committee, but the overall conference may be coordinated by the dealer association. Attendance may not be restricted to dealers only, but

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most industry groups do not encourage farmer attendance. Often, the top one to three people within a dealership will attend. A registration fee ($15-$60) is usually charged and a trade show of related equipment and products is often a part of the activities.

2. Area dealer meetings or clinics are conducted in many states. These meetings usually are coordinated by state specialists but are strongly aided by county faculty for publicity and local arrangements. They provide dealers with an update on current university recommendations or programs. Some applied research topics may be included. Historically, these meetings are attended by more of the sales people and agronomists associated with dealerships. In Wisconsin, separate programs are run for pesticide dealers, fertilizer dealers and seed dealers, although some of the same people may attend each. A small registration fee ($3-$5) is charged.

3. Most land grant institutions have designed active applicator training programs that promote the safe handling, storage, application, and disposal of agricultural chemicals. Although most of these programs were designed to allow both commercial and private applicators (farmers) to purchase and apply pesticides classified as "Restricted Use" by the Environmental Protection Agency (EPA), training programs are often broader than the minimum competency standards needed to satisfy state-mandated requirements and apply to restricted and non-restricted agricultural chemicals as well. The programs are developed and coordinated at the state level, but may be taught by county faculty (private applicators).

4. Dealers, agricultural consultants, and farmers can attend scout training schools that provide training in the principles of

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Integrated Pest Management (IPM) - a management system that reduces the reliance on a single-approach technique (e.g. pesticides) to manage agricultural pests. Clientele learn to identify pests and their damage, pest life cycles, pest management alternatives, economic injury levels and economic thresholds, and scouting techniques. These (two- to five-day) workshops are also used to train college students and others interested in working as summer field scouts. Industry demand for these trained individuals is very high, but participation by students appears to be declining coincidentally with the reduced enrollments in production agriculture departments. These scouts may work directly for farmers or for agricultural consultants, agricultural chemical dealers, or pesticide manufacturing company field representatives.

5. Special dealer training seminars which provide basic fertilizer, soil fertility, or pesticide information to new employees have been conducted in some states. Variations of these workshops include advanced courses with in-depth information on more specific topics such as nitrogen, fertilizer placement, or fertilizer management for specific crops. These programs may be developed for any need that arises. For example, a special series of programs have been conducted in Wisconsin since 1986 to help dealers understand the requirements, design, and the maintenance for fertilizer and pesticide secondary containment facilities. Initially, these programs emphasized the newly-developed rules and facility design needs, but the last two programs have shifted emphases to record keeping, spill and crisis management, and maintenance of facilities. These one-day sessions were conducted by state faculty and agency personnel and a modest registration fee was charged ($15).

6. Fertility management programs for dealers also occur as part of company-sponsored programs or training sessions. Many of the regional cooperatives and a few of the private companies hold sessions for their employees or customers at which Extension specialists provide a portion of the educational program. In some cases, special update sessions are also held where management or training personnel are apprised of changes, new information or developing trends as perceived by university faculty.

7. Fertilizer and pesticide dealers also serve as an educational link to farmers through the sponsorship of local producer meetings. Many county and state Extension faculty provide agricultural production information at dealer sponsored functions such as customer appreciation days. While this education is oriented primarily toward the farmer attendees, the dealers are also being exposed to the Extension message. Such forums are important Extension vehicles because they tend to improve dealer/university relations, attract large farmer audiences, and resolve misunderstandings or conflicts in recommendations.

8. Demonstrations continue to be a part of Extension efforts. These are often conducted in cooperation with local faculty and dealers for other audiences such as farmers, although sometimes the demonstrations are aimed particularly at dealers. For example, Purdue University has developed a large demonstration program on crop problem diagnosis. This facility draws dealer and producer employees for one to several days of classroom and field training. Demonstration plots graphically illustrate many of the common nutrient and chemical problems a field agronomist or sales person might encounter. Substantial registration fees are charged ($2,000 for each training day) with up to 50 people attending.

9. Newsletters have been particularly effective in keeping industry informed on current crop or management problems, regulation changes, or seasonal reminders. Slide sets, Extension fact sheets and other publications, video programs and computer decision aids are also used with agribusiness clientele, but are more commonly developed for other audience groups such as farmers or other ag professionals.

B. Organizations providing dealer education

Although vocational-technical agriculture, agricultural consultants, and a few other private and public institutions are involved, most of the research and educational activities associated with fertilizer and pesticide management are conducted by the applied research and Extension arms of land grant universities. The programs listed above are all examples of these Extension efforts. Not all are occurring in all states nor is any one state providing all of the programs or examples cited. However, the previous listing does provide a cross-section of the kinds of efforts conducted especially in the midwest. Product manufacturers are also involved in education by providing specific product information to dealers and farmers. Even when this occurs, product efficacy is usually verified and the information disseminated by university applied research/Extension programs. Some workshops and dealer-oriented training are being conducted by consultants on a fee basis, especially in states where Extension contact with industry is small. State or national fertilizer or chemical organizations such as the Illinois Fertilizer or Chemical Association, or The Fertilizer Institute may be partners in some training programs, particularly in identification of program need and development of program content. Such joint ownership is seen as a critical link between dealers and the university for improving mutual understanding, communication, clarification of issues, and establishment of credibility.

The diverse nature of issues associated with groundwater and surface water contamination with agrichemicals necessitates a coordinated systems approach among land grant colleges, Soil Conservation Service (tillage and soil erosion programs), Agricultural Stabilization and Conservation Service (cross-compliance programs), state Departments of Agriculture or Departments of Natural Resources, and local organizations such as Soil and Water Conservation Districts. Although rules development, program description, or policy creation responsibility for various soil, water and agrichemical issues have largely resided in other agencies, the educational efforts conducted in conjunction with such programs have traditionally remained with Extension. In many instances, Extension and/or applied research faculty contribute to and are a part of the development, description, and creation process as well. Occasionally, conflicts have arisen when agencies expected Extension to aggressively "promote" some program rather than simply educate user groups as to its strengths, weaknesses, or ramifications. A recent example was the rather severe criticism of Extension by ASCS officials in some states for the low participation in the 1986 Dairy Whole Herd Buyout Program.

C. Problems associated with dealer education

1. Lack of information. Major problems result from gaps in the data base. A University of Wisconsin Water Resources Center review concluded that the scientific data base is inadequate to determine how and where fertilizers or pesticides can be used without risk to groundwater or

to evaluate the health and environmental risks associated with groundwater contamination (Chesters et al., 1989). Nor do we have the data base to teach dealers and farmers everything they need to know about avoiding environmental contamination with agrichemicals. Surface waters can be contaminated by nutrients and pesticides carried in solution during run-off, in association with sediment in the run-off, in solution with groundwater and eventual discharge to surface water, and by volatilization into the atmosphere, followed by deposition into surface water. It is unclear as to what site-specific factors control the movement, degradation and/or deactivation of some pesticides. It is also not known what impact modifications in production practices will have on the degree or extent of the contamination. How well do the proposed best management practices work? Significant time may be needed to determine the effectiveness of such changes, especially where groundwater impacts are involved.

Of all the potential groundwater contaminants, nitrate is the most common throughout the U.S. (Blodgett and Clark, 1986; Hallberg, 1986). Intensive farming associated with modern agriculture has been linked with increased levels of nitrate in groundwater (CAST, 1985), however the extent to which practices increase groundwater nitrate levels is not well defined and often controversial. For surface waters, phosphorus has been identified as the most critical nutrient to prevent as a component of run-off (Schmidt and Sturgul, 1989). Evaluations are needed of new predictive tools for establishing nutrient needs. Determinations must be made on the fate and impacts of applied nutrients in various soil and crop settings. Can some crops be grown in certain areas without the threat of water contamination?

Weed management programs to reduce the amount of herbicide used in fields are underway. This kind of research points out a greater need for an interdisciplinary cropping systems approach than has been previously needed with more simplistic approaches to weed science (Schmidt and Sturgul, 1989). For example, University of Wisconsin studies using reduced herbicide rates for irrigated potatoes grown in sandy soils have shown that the resultant somewhat greater weed pressure also results in an increased risk of insect and plant disease problems (Stevenson et al., 1988). There is a need for extensive research that examines the interactive nature of all cropping components and their potential water quality hazards and benefits. There are many factors that influence how farmers select herbicides, such as cost, past experience, performance, advertising, etc. There is, however, little available information to develop criteria which allow us to add the potential for leaching to the selection process (Schmidt and Sturgul, 1989). Although there are considerable laboratory data available, there has been little field research to evaluate the effects of appropriate management practices on water quality.

2. Need for new technologies. Mixing/loading sites are a major point source of groundwater contamination with pesticides. Twenty-two Wisconsin sites have been identified where improper storage, disposal or handling of pesticides have caused groundwater contamination (Zuelsdorff, 1989). Although containment pads are being built for these sites, it is not known if the construction materials being used will withstand long-term effects of weather and frequent use. Additional work is also needed to develop portable containment systems for use by aerial applicators. Aerial

applicators often use local airstrips or growers' fields for landing and do not return to a permanent base for mixing, loading, and rinsing. Improper handling of wastes generated by rinsing tanks, equipment and pesticide containers can result in serious human health concerns and environmental contamination (Schmidt and Sturgul, 1989). Although guidelines for reducing wastes from pesticide application are available (Zuelsdorff, 1987; Doersch et al., 1988), these guidelines may be impractical for some operations. Sprayers that inject pesticides into spray water during the spraying operation can considerably reduce the problem of leftover spray mix. However, a completely acceptable prototype is not available at this time.

Emptied pesticide containers contain pesticide residues, and if disposed of in this unrinsed state can contribute to groundwater contamination. Although satisfactory rinsing protocols are recommended and available, unrinsed containers still find their way into the system. Returnable and reusable mini-bulk containers can alleviate this problem, but may contain greater quantities than needed by small farmers. Furthermore, multiples of the quantity of material packaged in large containers may not suit the size of the individual farms. Because of the large size of these containers, extra precautions may be necessary to prevent leaks and spills.

Fertilizer nitrogen recommendations are usually based on the crop's need for N (yield goal) with some consideration for the soil's ability to supply N. In some cases, credits are given for residual N stored in soil, rotational crops such as the addition of N from legumes, or applied waste materials such as manure. Farmer acceptance of these credits has been less than desired due to the difficulty in obtaining deep profile N samples, lack of farmer confidence in the uniformity or quantity of manure applications, grower inability to accurately assess the legume stand density, and the desire to use these "extra" nutrients as a bonus or hedge in anticipation of an excellent growing season. The development of a computer decision-aid system for better determining N fertilizer needs and the development of a rapid, easy to conduct soil sampling system which better estimates soil available N could help significantly in minimizing over application of N (Oberle et al., 1987; Bundy et al., 1989).

3. Shortage of applied research and Extension funding. New research initiatives are needed to improve pesticide practices and to develop new pesticides that are less mobile, less persistent, more specific to target pests, and less toxic to non-target organisms (National Coalition for Agricultural Safety and Health, 1988).

There is a critical need for increased funding for research on pesticide transport, degradation pathways and toxicity of metabolites. Our ability to detect residues is considerably greater than our understanding of what these residues mean. With no support funding for research in this area, little progress will be made in reducing pesticide impact on the environment. Although land grant institutions have the basic prerequisites to conduct needed research, funding and positions are needed for both basic and applied research, and Extension activities. However, land grant institutions are experiencing position freezes and cuts, declining budgets, or at best static funding. For example, in 1980-1981 the University of Wisconsin Agriculture/Agribusiness program area had 98 full-time equivalent faculty doing Extension programming. By 1987-1988, this number was

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diminished to 62 (UWEX, Staffing Plan 1987). Research and Extension activities that currently take place are often in addition to numerous other high-priority responsibilities. There is a misconception on the part of many government leaders and the general public that because only 2% of the population is involved directly with agriculture, and we currently have surplus production of some commodities, that there is a reduced need for funding and positions to drive research, teaching, and Extension activities at agricultural institutions. In actuality, problems are considerably more complex than those experienced even 10 years ago and often take more time, planning, research, and interdisciplinary interaction to solve.

Some basic and applied research has been initiated which examines the principles and efficacy of various methods of nonchemical nutrient and pest management. Although potentially effective, these methods tend to be extremely management intensive (Francis et al., 1987). Further development and adoption of these techniques may provide a basis for new or expanded management service by the agrichemical industry. However, acceptance and implementation of these techniques will also likely require additional applied research and substantial demonstration of their applicability (Kelling, 1989).

The numbers of county and state Extension positions continue to decline, and although the Extension service prides itself in program planning and priority setting, it may have reached a point where there are too many items with a "top priority" and too few people to adequately serve and educate the public. In addition to their still-important, more traditional responsibilities, Extension state staff specialists at most institutions now conduct much of the applied research necessary to provide the data base for their educational programs. While this shift in responsibilities has been desirable from the perspective of program ownership and identification, it has been done at the expense of time available for Extension activities and commitment to Extension. Funding for such applied work is difficult to procure; competitive grants for mission-oriented research are essentially non-existent. In some cases, the results, although critical for the well-being of both rural and urban agriculture, are sometimes not publishable in the scientific literature. Because academic merit of researchers is usually scrutinized in terms of numbers of publications and competitive grants awarded, it is understandable that a new researcher may be reluctant to spend significant time on applied research, or working with the general public on resolving these real-world problems.

4. Addition of new programs or requirements. Although pesticide applicator training programs offered by states currently meet U.S. EPA training requirements, new federal initiatives will require revamping and expansion of existing training. Worker protection standards, right-to-know rules, Superfund Amendments and Reauthorization Act (SARA), groundwater protection, and endangered species protection requirements must now be included in the training and will require greater time commitments from trainers and participants. Training programs currently take most of a day and none of the existing subject matter can be dropped to accommodate the new initiatives. An additional time commitment from trainers and participants will be necessary. Extension will need to increase training requirements or lose approval of their program, while facing local political pressure to reduce both training time and charges for growers, and dealers.

5. Reduced interest in production agriculture. The use of field scouts in IPM programs will occasionally increase pesticide or fertilizer use; however, the end result of such programs usually results in reduced and more judicious use of agrichemicals. Private consultants, agricultural chemical dealers, and Extension pilot IPM programs are currently facing a shortage of trained field scouts. This is in spite of the fact that most colleges of agriculture sponsor scout training schools for students and non-students alike. An illustration of this trend is shown by enrollments in the three University of Wisconsin scout schools which is down nearly 40% from the high enrollments (100-120 students) of the early 1980's. (B. Jensen, UW Entomology personal communicator). Competition for trained scouts is keen, and anyone wishing to work as a summer field scout can find work. Part of the problem may be the result of a declining rural school-age population which is reflected in decreased enrollments at colleges of agriculture, especially in programs related to production agriculture. Such drops in enrollments are evident at all levels of education (B.S. through Ph.D.) and some concern exists that qualified faculty specializing in production agriculture will not be available to replace faculty who will retire in the early 1990's. Production agriculture programs are apparently unattractive to prospective students even though jobs exist in this area. This situation may be cyclical and a result of the recent problems in the agricultural economy.

6. Current policy within Extension. In an attempt to make federal and state Extension programs more relevant and accountable, the concept of issues programming has evolved (Geasler, 1982). This concept calls for a small core of relatively flexible specialists to determine

programming needs, provide program leadership and coordinate the activities of short-term people hired to fulfill the specific program needs. Once the program has met its goals, these people would be released or moved to a new project. This concept ignores the successful development of a working rapport with clientele groups that lies at the heart of successful Extension programming. Clientele groups use Extension because they have gained confidence in the organization and the individuals associated with it through the development of long-term working relationships. It takes significant time to develop this level of confidence. Jumping from one audience group to another to satisfy only the immediate needs of the current hot issue seriously erodes this relationship. An Extension strength lies in the fact that it historically has relied on "bottom-up" development of programs to meet clientele needs. In issues programming, it is important that this is not lost and replaced with "top-down" development of perceived issues.

In recent USDA-CES documents addressing the need for and challenges associated with Extension programming in water quality, the message is most clear that programming in this area is needed, but was very mixed as to which audience groups should be served (Extension Service 1988; ECOP, 1988). Both reports indicate that CES needs to provide educational programs that result in actions to improve water quality and that create and sustain a public commitment to enhanced water quality; however, the specific direction and thrusts of these programs is properly relegated to state and local discretion. Suggested potential audiences include agricultural producers, agrichemical dealers and custom applicators, householders, local governments, consumers (general public), land managers and state agencies. It is our belief that given the diversity of needs and opportunities for water quality programs, Extension will need to carefully choose those programs and audience groups they wish to serve. An important issue to be answered will be whether directed programming such as water quality will be aimed at traditional audiences or if Extension will try to expand into audience groups who have not been long-term Extension users. In some states, agrichemical businesses may be considered a traditional audience whereas in others it may require new monies or reallocated resources.

7. Lack of dealer incentive. Some form of incentive must be present for dealers to sell fewer chemicals. Although most dealers do not currently sell chemicals with disregard for the long-term economic health of customers, they are nonetheless in business to sell farm supplies. Dealers currently serve as a source of "free advice" for growers. In the future, they may need to charge for this service. For example, a grower might be advised that past plant tillage cultivation may complement a lower herbicide rate and prove equally effective as a higher rate of herbicide. The dealer may have to charge for such prescription weed control. Economics drive the system; a farmer does not have the time or expertise to make all crop production decisions unilaterally. He relies on the dealer to help with many crop related decisions. Universities capitalize on this pyramid-like system of providing educational information to consultants and dealers for their transmittal to growers because Extension does not have the personnel, travel budgets, nor time to work one-on-one with all growers. Once data are released by the university, economics and practicality determine if that practice is adopted by the private sector.

This type of scheme allows the industry to substitute the sale of service for the sale of products. It also occurs to us that this system may work best if all industry participates in charging for services. Furthermore, universities may stimulate movement toward this opportunity by similarly charging for recommendations.

D. Recommendations for future agrichemical dealer Extension programs

1. Information needed. There is a key need for dealers and consultants to be aware of the factors that contribute to contamination of groundwater by nutrients and pesticides. The phenomenon cannot be explained by product solubility alone because rather non-soluble pesticides can also reach groundwater. Solubility, soil reactions, adsorption, volatility, transformations, and persistence are all involved. Field site, soil, hydrologic and geologic characteristics also must be considered for the proper assessment of a chemical's potential for groundwater contamination (Schmidt and Sturgul, 1989). Dealers must understand that pesticide load in run-off is affected by the time, type, frequency, and intensity of various farming operations. For example, a survey of all Iowa public water supplies determined that surface water was more frequently contaminated with pesticides (63% of the supplies utilizing surface waters) than groundwater (Fawcett, 1988). Spencer et al. (1985), however, reported that except where heavy rainfall occurred very soon after application, pesticide concentrations were very low and the total amount of pesticides removed from the land in run-off during the crop year was usually much less than five percent of the application (Kinsell, 1980).

Current data suggest that most groundwater contamination results from point sources of pollution. Many states are enacting containment laws requiring that mixing and loading sites, and storage areas must be protected by impervious dikes and pads. Dealers need to understand the best methods available for reducing risks at these locations. Rinsing sprayers in the field allows rinsates, excess spray mix, and effluent to be used in the field in accordance with pesticide label directions and state and federal law. It also removes the activity from vulnerable well sites. Operators also need to be familiar with methods of dealing with spills and other emergency procedures.

Improper calibration or excessive application may result in carry-over of fertilizers and pesticides, cause crop damage and increase the potential for groundwater contamination. Substantial environmental contamination with pesticides and fertilizers results from inappropriate management practices. Applying only the needed rate of nutrients is the single most important nutrient best management practice (Schmidt and Sturgul, 1989). Pesticide users must always read and follow label directions, mix and calibrate accurately, prevent spills, use proper waste disposal, and consider weather and irrigation effects on surface water. Water sources must be protected by anti-siphoning devices. Pesticide storage facilities should be placed well away from and down gradient from water supplies and other sensitive areas. Emergency response plans must be developed, pesticides must be transported safely, and pesticide containers must be rinsed and disposed of properly. Dealers also need to remind farmers of these techniques and requirements. The dealer is usually the last person advising a farmer before he purchases and/or applies a pesticide.

Dealers need a thorough familiarity with relative merits of various alternative fertilizer and pest management practices - crop rotation, utilization of planting dates, use of manure, control of weeds harboring pest insects, alternative nutrient sources, timing of harvest, tillage, biological controls, all need to be considered before the farmer makes the ultimate management decision. Dealers need to become more adept at fitting many individual component decisions into an overall systems-approach management program.

IPM is an example of overall pest control which considers all alternatives when formulating a control program. It involves chemical and non-chemical control methods, and application of chemicals only when absolutely necessary. Insurance applications of insecticides are used only as a last resort and only with the most selective compounds available. Complete elimination of the pest is unnecessary, and the small reservoir of pests that remain helps maintain a population of beneficial insects. Positive and accurate pest identification is a prerequisite for IPM programs as is an understanding of economic threshold and economic injury level concepts.

Similarly, fertilizer and weed control programs should not be approached as single entities, but as part of a systems approach that utilizes good management programs throughout the season. Such programs include variation in row spacings, proper plant densities, proper seedbed preparation, adequate but not excessive nutrient application from all sources, and appropriate disease and insect control. These practices promote vigorous crops that compete well with weeds. The goal of such cultural practices is to establish a profitable vigorous crop that competes well without undesirable impacts.

Recent findings in groundwater and surface water contamination with agricultural chemicals has provided impetus for a systems approach to evaluating chemical inputs and the development of best management approaches to managing crop pests and fulfilling its nutrient requirements. In other words, the most effective approach may not always be the best one when all factors are considered. Continuing efforts are going to be needed for the identification of key factors that lead to groundwater contamination with the objective of developing site-specific recommendations for the best nutrient management and the control of crop pests. Cultural practices such as use of crop rotation, appropriate crop selection and use of cover crops, in addition to holding soil in place, can be a part of a crop management program that reduces fertilizer and chemical use. Dealers must be made to recognize the longer term benefits of such practices in contrast to their short-term loss of sales. If dealers are going to substitute better service as a profit generating mechanism for product sales as an economic survival strategy, Extension will need to provide additional help in several ways. Most importantly, Extension in consort with regulatory agencies must be prepared to supply the dealers and consultants with the means for determining and providing profitable and environmentally acceptable alternatives and recommendations for specific fields and farming enterprises. Best management computer-driven decision aids and economic threshold determinations will need to be developed or expanded. Soil test recommendation programs will need to be reviewed in light of both economic and environmental considerations. Dealers will need to become increasingly skilled in farm management and financial counseling techniques. Extension currently provides this type of training to its county faculty, and to some extent to agribusiness (see Section II). However, if this strategy is to be employed, this role will need to be greatly expanded. As the link between research and the end user, and as the outreach educator, Extension is best equipped to serve this role.

2. Extension needs for delivery. Extension has the framework, experience, and talent to accomplish the stated educational needs. What it lacks is stability, augmentation with permanent funding, faculty positions, and strong, effective leadership at the state and federal levels. Current emphasis on "issue programming" may be an acceptable strategy, but there is a very real risk that the "issue" and the clientele group will remain long after the popularity and funding has faded. Such ambitious programs should not be undertaken with "soft" dollars. An analogous situation exists with pesticide applicator training and IPM programs, for which federal funding has been awarded on a formula basis. Funding for private and commercial applicator training has almost disappeared and dollars for state IPM programs are tenuous at best. The demand for programming in these areas remains high, but these programs have never reached their full potential because they have not been supported by a permanent budget addition.

3. Staff needs. Faculty needs will vary with states, but, at the very least, each state should have a full time program coordinator to deal specifically with dealer training and with some budget for technical and clerical staff. This role should be considered as a new position and filled by a person who already has significant Extension experience. He/she may conduct some applied research as well. The coordinator should be trained and/or experienced in production agriculture and/or pest management, but with a sensitivity to environmental protection. This individual should also be able to conduct and coordinate applied research because it will be necessary to work with subject matter specialists in interdisciplinary programs. Some states will not have personnel to address certain issues, so the coordinator will also have to locate and coordinate input from subject matter specialists from other states.

Particular agency staff members may contribute to educational programs; however, educational leadership and primary delivery should continue to reside in Extension.

State and local commodity organizations, fertilizer and agrichemical associations, and professional consultant groups need to continue to be involved with programming efforts as they have in the past. This will provide an immediate feedback mechanism for the usefulness, practicality and appropriateness of developed materials or programs.

5. Delivery mechanisms. The existing education and information vehicles used by Extension will also work for these programs. As new technology and management techniques develop, there will be an increased need for direct farmer contact. During a recent series of meetings seeking input for research and Extension needs in sustainable agriculture, it was very clear that farmers wanted more individual contact and personal help in developing management strategies and implementation plans, and that hands-on, show-me demonstrations are desirable (Kelling, 1989). Both of these techniques require significant numbers of personnel. Dealers can provide an invaluable service as both an audience group and a transmitter of information by both methods.

Development of computer-assisted decision models will need to be accelerated, and agribusiness will need to be trained in their use. To some extent, dealers already use farm record keeping and recommendation programs for their customers. However, additional programs will be needed to educate dealers on the computer tools which try to zero in on specific crop and field agrichemical needs. Use of programs such as Potato Crop Management (Stevenson et al., 1988) and Nutrient Adjustment Worksheet (Schulte et al., 1988) will expand.

Additional research and Extension specialists are also needed to develop and evaluate production best management practices relative to their impact on groundwater, surface water, and other non-target areas; develop and/or evaluate negligible impact practices for susceptible areas; and develop and conduct educational programs on water quality and best management practices for dealers, county Extension agents, agricultural consultants, farmers, environmental groups, and the general public. All of these positions should not be filled with M.S.-level people capable only of program delivery, as these individuals would not have the research base or the personal ownership of the program for effective delivery. Each state will have to carefully consider its program development and applied research needs relative to the needs for program delivery. The actual staff hired will be dependent on the identified needs.

4. Other agency involvement. Because most land grant institutions have the basic organization, talent, and experience needed to conduct such large interdisciplinary projects, it is appropriate that leadership for development of these programs reside with Extension and land grant institutions. It will, however, be important to develop and deliver these programs in close coordination with the appropriate state and federal agencies including the EPA, U.S. Geologic Survey, Soil Conservation Service, Agricultural Stabilization and Conservation Service, state Departments of Natural Resources, and state Departments of Agriculture. In many cases, these units are charged with regulatory responsibilities for various aspects of water quality. Cooperative efforts with these agencies that are involved in the development and enforcement of pertinent rules lead to better understanding and even expanded levels of cooperation.

6. Program evaluation. Evaluation of the success of such programs is difficult. One is trying to measure a change in awareness and attitude of people as a consequence of program effort. Furthermore, these changes are expected to bring about changes in practices or actions by the clientele groups (ECOP, 1988). Surveys of this nature are difficult to design and interpret, but they will need to be done. Baseline data will need to be carefully collected and then followed with measurements of changes in client activity.

The ultimate measure of the success of these programs will be the subsequent trends in the quality of our groundwater and surface water. Intensive, long-term monitoring of these natural resources will be an important, integral part of these projects. Many states already have monitoring programs in place and then data should be used where applicable.

III. Suggested administrative actions to foster dealer education programs

Policy makers and agency or university administrators need to recognize that the way in which formula and competitive funding are distributed makes it very difficult for land grant institutions to address issues such as those described in this paper. What often happens is a reshuffling of scarce resources and positions with an add-on of responsibilities to present staff. The allocation for "agricultural" research must be carefully scrutinized. National Science Foundation (NSF), National Institute of Health (NIH), USDA Competitive Grants, and similar sources generally fund only very basic research. Proposals for basic research addressing prevention or amelioration of groundwater contamination with commercial fertilizers and pesticides would not be funded because they

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are not sufficiently theoretical to meet granting parameters of these institutions. Furthermore, some of the funding that land grant colleges receive is earmarked to the point that administration has limited latitude in shifting resources to meet local needs. There is a critical need for a system of formula funding and competitive grants to assist land grant institutions in dealing with the economical production of agricultural commodities in a system that considers and protects natural resources. Perhaps there needs to be an evaluation of our current funding system to see if research needs are being met by present funding sources, or whether earmarked funding predetermines the kinds of research that are done. Land grant institutions must maintain strong basic and applied research programs.

As colleges of agriculture expand their expertise and productivity into such areas as molecular biology, biotechnology, etc., it must not be at the expense of mission-oriented research that addresses day-to-day problems in production agriculture, sociological issues, revitalization of rural America, and the delivery of these programs to appropriate clientele. University administrators must remember that within public institutions, the role of the public service and education component is a significant responsibility, and that this component is very important in determining how citizens perceive their land grant institutions.

Once mid-career and older state staff Extension specialists retire, there will be few people left at the university level who have the training and understanding to work with a combination of production agriculture, integrated pest management and environmental protection, or even have the willingness to do so. Government and university administrators must recognize the critical role that these positions play in rural and urban agriculture. They must not overlook this need and should provide rewards and advancement for people who do work in these critical areas of research and outreach.

Specific potential actions at the federal level may include:

1. Developing regulations that govern the use and management of fertilizers and pesticides. This approach, while possible, would be difficult and probably not very palatable. Such regulations would need to be sufficiently broad to be sensitive to local needs and environmental conditions. Historically, rules which have tried to dictate good management systems have been either overly complicated or ineffective. Enforcement would be difficult, costly, and onerous.

2. Increasing educational programs that emphasize the link between agrichemical use and improved management and water quality. Although some programs currently exist they could be expanded and better focused. Specific efforts towards farmers, agrichemical dealers, and homeowners should be advanced.

3. Developing federal water quality standards for pesticides and nutrients. Standards must be established which safeguard the public waters but do not overly restrict the use of materials important to competitive agriculture. Agricultural products compete in the world marketplace and U.S. farmers must remain competitive.

4. Increasing funding for applied research which delineates the water quality risk or benefits associated with agrichemical use. Changes in certain management practices may result in reduced potential for water

contamination with nutrients or pesticides. Evaluation of such techniques on a local basis is important for farmer acceptance and adoption. See Section IIC1.

5. Providing appropriations commensurate with educational program needs. The Cooperative Extension Service-USDA should be authorized or requested to develop cost estimates, in conjunction with several states, for the provision of adequate programs in pesticide education, nutrient management education and other aspects of agricultural impacts on water quality. These should include both farmer education and agrichemical dealer education and should include estimates of the administrative staff needed to administer such programs.

6. The Cooperative Extension Service-USDA should direct its water quality educational programming towards those audiences such as agrichemical dealers and farmers that can have the largest impact. Clientele rapport and trust are important. CES should build on the strengths it already possesses. Even within the context of expanded resources, it is not possible to meet the needs of all groups.

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COMPUTER-BASED DECISION SUPPORT SYSTEMS FOR FARMERS: APPLICATIONS FOR GROUNDWATER PROTECTION

by

Bernard Knezek
Crop and Soil Sciences
Associate Director, Kellogg Biological Station
Michigan State University
East Lansing, MI

J. Roy Black
Agricultural Economics
Michigan State University
East Lansing, MI

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I. INTRODUCTION

Farmers use a variety of information sources to make basic decisions about their farm business, but few can readily obtain the essential information and manipulate it in ways that result in optimal management decisions. Most must forge ahead with the information at hand, however sketchy or disjointed it is, opening themselves to risk of a poor decision and possibly reducing farm efficiency.

Farm managers' need for more and better information has grown with concerns about the environmental impacts of farming operations, such as nitrate and pesticide contamination of groundwater. Legislators and regulators are considering a range of policy instruments to reduce the potential for groundwater contamination, including restrictions on pesticide use, limits on nitrogen use, restrictions to choices among best management practices, sampling and monitoring, and groundwater quality standards. All changes would require farmers to take even more factors into account when making management decisions.

Researchers in the public and private sectors are working to improve the decision support "tools" available to farm managers and those working with farm managers. New tools include monitoring and control devices, computers, application and database software, and communication links interconnecting these elements. This paper focuses on a new concept for integrating these tools, Decision Support Systems (DSS), and its application to groundwater protection in agriculture. DSS are primarily computer based (in agriculture, primarily microcomputer) programs and supporting data bases used in support of management decisions.[1] Components of the system can be used individually, such as making improved nitrogen and pesticide use decisions, or jointly, and share data bases.

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[1] The concept of decision support systems evolved out of dissatisfaction with the more structured concept of management information systems. In some of the management and information systems literature, DSS refers primarily to tools for interactively querying data bases and analyzing alternatives for relatively unstructured questions; also, they specifically focus on flexibility and adaptability to accommodate changes in the economic and technical environment. Instead of defining a new term, such as management support systems, we have chosen to place the wide array of computerized tools and supporting data base concepts (e.g., transactions processing systems, expert systems, management information systems, geographic and other spatially oriented information systems decision aids) used in support of the decision making function under the umbrella of the term decision support. Many authors have adopted this approach. The DSS concept is discussed in section III.A.

Several distinct classes of information systems have emerged through efforts to apply increasingly sophisticated computer hardware to agricultural problems, while striving to put data-processing operations under the direct control of farm users (e.g., as contrasted to mail in record systems that have evolved in the areas of farm accounting and dairy herd management). The three main classes of information systems are:

TPS - or transaction processing systems for gathering, updating, and posting information according to predefined procedures. Software within this class includes field records and farm service center records.

DSS appear to have high potential for addressing environmental considerations in agriculture because they are capable of handling both specific, structured questions aimed at identifying best management practices for a given operation, as well as less structured questions about how a strategic farm plan could be revised to reduce the need for chemical fertilizers and pesticides. For the potential to be fully reached, however, additional models will need to be developed to cover the broad range of decisions farmers must make, existing models often need to be enhanced to reflect a broader range of management alternatives and environmental considerations, and the supporting data bases need to be improved. The education and training of farmers and those working with farmers in the use of those tools will be an equally important component in the evolution of farmer's approach to decision making.[2]

The paper begins with a review of the evolution of computer use in production agriculture in order to have a baseline for exploring future use. This section includes a review of the extent of current microcomputer use by farmers, an overview of the number and locations of vendors of agricultural software, and a listing of some of the on-line (accessible by microcomputer via modem) databases available to farmers and those who work with farmers. Next, the organizational concept of decision support systems is discussed; some of the currently available components are described. The fourth section of the paper focuses on groundwater protection applications of DSS. The last section describes a prototype integrated DSS that is under development on the Dairy/Crop Farm at Michigan State University's Kellogg Biological Station to illustrate how environmental and farm operation data can be integrated in software programs useful to farmers.

MIS - or management information systems that have predefined systems that have predefined analysis and reporting capabilities. Tasks such as preparing financial summaries and summaries of weed incidence and nitrogen use by field and the labor use profile for the year are examples.

DSS - or decision support systems with extendable, built-in capabilities to support data gathering for TPS; information processing vis MIS; application-specific analysis and reduction of data to aggregated summaries; and decision-modeling activities. Tasks such as evaluation of weed, insect, nematode and disease control options, irrigation scheduling and choice of level and timing of nitrogen application are examples.

Full-fledged, whole farm versions of DSS software remain to be built and tested.

[2] Models, databases and training are limited by our knowledge base. For example, our understanding of the movement of pesticides and nitrates through the soil has improved markedly in the 1980's, yet quantitating the movement, particularly below the root zone to groundwater is quite imperfect except in obvious cases. Thus, development of a better qualitative and quantitative understanding will be crucial for improved models and supporting databases.

II. MICROCOMPUTER APPLICATIONS IN MANAGING FARM BUSINESSES

Farm level decisions can be enhanced by computer systems and supporting interactive software that includes integrated management models and databases. The use of microcomputers in agriculture has been widely touted for a decade. After a number of "false starts" ownership appears to be increasing, providing a support base for future expansion.

This section discusses the computer applications by farmers during the 1960's and 1970's that set the stage for the introduction of on-farm personal computers in the 1980's. Surveys of the extent of farmer adoption over the course of the decade are discussed next; the kinds of applications farmers made such as accounting, financial projections, and crop and livestock management "decision aids" are discussed. The next sections lists agricultural software vendors and some of the major "on-line" data bases that are available to farmers with computers and modems. The last section brings attention to the implications of the structure of agriculture and of the cost of hardware and software for purchase and application by farmers. These sections set a reference point for assessing the prospects for increased microcomputers use in production agriculture in the 1990's.

II.A. Setting The Stage: Computer Use In Agriculture Prior To 1980

Computer use in commercial agriculture was primarily in three areas prior to 1980. First, when use of mainframe computers became economically viable in the 1960's, university,[3] and private sector organizations and university-private sector consortiums offered mail-in farm record and accounting services (Harsh, 1989). Many of these were a component of farm record association programs where a fieldman worked closely with approximately 150 farmers. Kansas, Illinois, and Minnesota were typical of this model. The Farm Credit System's AGRIFAX system and Farm Bureau Systems were typical of private sector initiatives. Many of these systems were upgrades and extensions of previous systems maintained by hand.

Most experts believe farmer's participation in these projects has been due more to income tax and other federal and state legal requirements than as a basis for management decision making. Management needs were important, but they were not the major reason for participating. Participation by farmers in states with viable and well supported farm record systems ranged from 8 to 35 percent of commercial farms (Hepp, 1988).

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[3] University systems were justified as facilitating an educational function, providing 'real' information on costs and returns, and studying managerial processes.

A second major area was the Dairy Herd Improvement Associations (DHIA) which provided (and, continues to provide) a mail-in record service on the performance of individual dairy cows and for the evaluation of bulls for use in artificial insemination programs. Participation varied across the United States, but represented about 40 percent of dairy cows. Certain other management information was provided, including recommendations for culling. These associations, like many of the farm record associations, were loosely tied to universities, with universities providing educational support and contributing significantly to prototyping and defining protocol that the system would follow. DHIA fieldmen made monthly farm visits to make the appropriate measurements.

The farm record and dairy record systems have microcomputer options in many areas of the United States in the late 1980's. Also, in some areas, the dairy record system may be accessed via a modem in a time-share computing environment.

The third major thrust was in the area of integrated pest management (IPM)[4], beginning with the introduction of time-share computing in the early 1970's. These systems were part of a much larger IPM research and education activity (Bird, 1989). In many states, considerable resources were put into the development and fostering of cooperatives and private sector pest management service firms that provided pest scouting and action guidelines to farmers. Here, pests are defined to include weeds, insects, nematodes, and plant diseases. Some irrigation scheduling services developed along this model too.

The role of the time-share computing environment included maintenance of on-line weather data and accompanying pest projection models to assist scouts in identifying pests to be scouted. These systems also included management models which could be used in conjunction with pest incidence models to project economic thresholds for taking pest control actions on the part of farmers. The focus was pest control programs based upon observation, followed by appropriate action as contrasted to lack of observation and blanket control.

The exception to the time-share computing examples discussed occurred primarily in California and some Southeastern states like Texas, Florida, Mississippi and Arkansas. There, some large farmers and consulting organizations had mini- and small mainframe computers as well as participating in a time-share computing environment. This was economically viable because of the large size of the farms, relative to much of the United States, and the high value and pest susceptibility of crops being grown.

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[4] IPM is a systems approach to reduce pest damage to tolerable levels through a variety of techniques, including predators and parasites, genetically resistant hosts, natural environmental modifications, and when necessary and appropriate, chemical pesticides.

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II.B. The beginning of the on-farm microcomputer era: microcomputer ownership and software applications by U.S. farmers during the 1980's

This section reviews studies of the adoption of microcomputers following their introduction in 1979/80. This transition reflects initial enthusiasm, particularly on the part of potential software vendors, many University Cooperative Extension Service specialists, and innovating farmers. Many changes took place as hardware and software evolved during the 1980's and as the utility of microcomputers and data acquisition were re-evaluated. The period was further tempered by the worst financial crises in US agriculture in 50 years.

Arthur Anderson/University of Illinois Study (1982)

The authors estimated less than three percent of commercial farms owned a computer in 1982. They projected one in six commercial farmers (17 percent) would own a microcomputer by 1987. Their study indicated common uses would include accounting, crop and livestock production records, forward planning (including cash flow, profit and loss, and financial balance sheet projections), and acquisition of market information for use in making pricing decisions.

Iowa State University Study (1982)

Bultena and Hoiberg's (1983) objective was to examine factors that distinguished adopters of computer technology from nonadopters. The sample was drawn from those farming at least 80 acres. There were 425 farmers in the sample.

Only 3 percent of the farmers in the sample were using microcomputers in their farming operations. An additional 10 percent said they were definitely planning to purchase a microcomputer and 7 percent were contemplating a purchase. One out of four farmers were not microcomputer users, but they had thought about how a microcomputer might be used in their farming operations. The largest group, 57 percent, had not given serious thought to how a microcomputer would be of use to them.

The adoption of microcomputers was related to size of farm business and the educational level and age of operator. For farms with over $100,000 in sales, 25 percent either owned or were contemplating buying a computer. The percentages were 13 percent for farms with $75,000 to $100,000 sales and 7 percent for farms with $20,000 to $75,000 in sales. Forty eight percent of farmers who were using computers were college graduates and

18 percent of the farmers who were planning to purchase a microcomputer were college graduates. In contrast, only four percent of college graduates hadn't given any though to purchasing a microcomputer.

The average age of farmers who purchased, or were contemplating the purchase of a microcomputer, was slightly younger (42 years old) than those who had decided against or hadn't considered purchasing a microcomputer (48 years old). The farmers who had purchased, or were planning to purchase a microcomputer, made more use of forward pricing mechanisms for the crops and livestock they produced than those who did not. Further, they made more use of more complex pricing mechanisms (futures contracts vs. cash forward contracts). Seventy five percent of the farmers who were using microcomputers used the futures market to price a portion of their grains or livestock. In contrast, only 15 percent of those who had not considered or rejected using computers used futures markets.

New York Study (1982)

Aldrich and Knoblauch's (1982) objective was to determine the current state of microcomputers use on farms, to gather data on the types of microcomputers used, to review the types of software in use and the vendors they were acquired from, and to identify software development needs. Farmers were identified who owned microcomputers and a mail survey was used; the response rate was 80 percent. The predominant farm type was dairy or dairy/cash crop.

The most common computer in use, by a large order of magnitude, was the Radio Shack (Tandy). Thirty eight percent of the farmers had written some of their own programs or spreadsheet templates. They included ration balancing, financial record systems, and animal record systems. Many farmers developed spreadsheet templates based upon University Cooperative Extension Service Fact Sheets; some used coding sheets that had been developed for programmable calculators as a point of departure. Purchased software was in the same application areas and in fertilizer recommendations and in support of insect management. One out of three farmers used spreadsheets (e.g.,Visicalc).

Software was acquired from two private sector vendors and a number of Land Grant Universities. The private sector vendors were Agway (a large farm supply cooperative in the northeastern US) and ConsulAgr. Universities included Clemson (accounting), Cornell (livestock records and management decision aids), Mississippi State (ration formulation, records, and budget generation) and Oklahoma State (records, cash flow projections).

Farmers stated the area of greatest benefit was in the area of record keeping, both financial and physical (crop and livestock) records. A major objective was to use the computer to gain control of the farm organization and thereby gain efficiency.[5] Important future objectives included developing the capacity of decision support aids to read information from and write information to data bases. Also, farmers wanted more capacity to generate management reports from their data bases. Real-time applications such as daily monitoring of milk production and animal health and feed control systems were cited as future uses. Automating equipment to "feed" and to "use" databases in arriving at control decisions was set as a target.

Eighteen County Indiana Study (1983)

The Arthur Anderson, Iowa, New York and Purdue studies were conducted shortly after microcomputer technology entered commercial channels. The Purdue study was designed to measure attitudes about farm microcomputer performance and collect information on farm computer users, computer hardware and software, and uses of the farm computer (Alderfer, 1985).

Seventy-eight farmers who owned microcomputers were surveyed; they were using 27 different models of computer hardware and a variety of commercial software. This lack of standardization reflected the lack of standardization during the early days of the microcomputer industry. The study was conducted at a time when farmers were starting to make the transition from the Radio Shack, Apple II and CP/M systems such as the Osborne and Kaypro II to IBM personal computers and associated clones. IBM personal computers started to became available in the fall of 1981.

Farmers making cash flow projections, financial balance sheets projections, and crop field record data applications had a more positive attitude about their systems than those who did not. Likewise, those with spreadsheets, larger capacity hardware and modems were more satisfied with their computer systems. Younger farmers, particularly those who used their microcomputers in cost accounting, had a more positive outlook regarding the farm computer. Formal farm records increased by 20 percent after computerizing. Many farmers substituted microcomputer accounting systems for mail-in systems in which they had previously participated.[6]

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[5] Lazarus and Smith (1988) studied New York dairy farmers use of their dairy herd improvement association records. Farmers who agreed or strongly agreed with the statement "they did not have enough time to study their records"; cows produced 6% less milk than those who disagreed or strongly disagreed with the statement. Farmers with more productive herds had the time *or* made an effort to allocate more time to analyze their records. The question responses may also be indicative of management capacity.

Iowa/New York Study (1984)

Scherer and Yarbrough (1984) further examined the adoption of microcomputers by farmers in Iowa and New York. The studies were based upon random farmer panels in Iowa in Winter 1982, 1983 and 1984. The usable sample sizes were 531, 368 and 325 in the respective years. These reflect response rates of at least 60 percent. The same procedures were used in New York in 1984. There were 630 respondents, which reflected a response rate of 70 percent.

The adoption rates for the random sample were 3, 5, and 7 percent in 1982, 1983 and 1984, respectively. Most farmers were aware of microcomputers. Seven percent of farmers were in an evaluation stage in 1982 and moved up to about 15 percent in 1983 and 1984.

The adopters consistently tended to be younger, have more education, and have larger farm businesses. Rejection was highest for older farmers, less educated farmers, and smaller farmers[7].

The percent of adopters who had prior computer experience was in the 40 to 50 percent range and it was 15 percent or less for those who had rejected purchasing a microcomputer. Those in the evaluation stage were intermediate. Use of cash flow analysis, enterprise accounting, and futures markets was greater by respondents who had purchased computers or who were in the evaluation stage.

Tulare County California Survey (1986)

An 18% random mail survey of farms in Tulare County, California was conducted in 1986 to estimate the extent of computer ownership and the nature of computer applications (Putler and Zilberman, 1988). Forty-five percent of the farms survey responded. Approximately one out of four farms owned computers.

Table II.1 depicts, for those farmers who owned computers, the percentage who used various applications. There was a large range in applications; three out of four farms used accounting software (e.g., general ledger and cost accounting) while less than one out of five used production management decision aids and/or crop livestock management software. Approximately six out of ten farms who owned computers used spreadsheets (e.g., Excel, LOTUS 1-2-3, Quattro, SuperCalc), with very high rates of application for college educated farmers. Table II.2 depicts the probability of accounting, spreadsheet, and production decision aid being used by a 41-50 year old farmer with no farm related businesses. The table is for all farms, not just those with computers. Computer application increases with farm size, farm operator education, and for multi-enterprise farms.

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[6] There is considerable anecdotal evidence farmers have made much more use of their records when they had more control over structuring them and being able to interactively query the data base. They also maintain more information in the context of "farm specific" decisions.

[7] Older farmers also tend to be less educated.

Computer application patterns differ, however, for the largest farm category -- those with annual gross sales in excess of $4,000,000. These farms made less use of spreadsheet data base management software than smaller farms. Interviews by the authors with experts in Tulare county suggest differences in patterns were due to type of computer used; the largest farmers tended to own mini- and mainframe computers while medium and smaller farms (by California standards) own microcomputers. Also, some dairy farmers make use of time-share computers for livestock records and tactical decision aids for selecting feeding strategies, making culling decisions, and creating "to-do" lists (e.g., list of cows for the veterinarian to examine).

Dairy farmers were the most likely to use decision support applications. This result was expected because many of these decisions are very structured (well defined) and the nature and form of the decision aids has evolved over the last twenty-five years. Many early mainframe prototype applications in the 1960's were in this area. Decision support applications became widely available under time-share computing in the early 1970's, particularly in California.

As the number of farm enterprises increases, the likelihood of using crop/livestock management applications increases. Increased complexity increases the need for tools to monitor and manage complexity. Similarly, ownership of farm related businesses significantly increases computer ownership and application. Owners of sales related businesses (e.g., packing shed) are more likely to use transaction processing applications such as payroll and inventory. Farms with pest control advice related businesses are more likely to own decision aid applications. Farms with farm management consulting related businesses were more likely to own spreadsheet and data base management applications.

The authors conjecture that the lower use of crop production oriented decision aids was due to the lack of adequate, field tested crop simulation models. These are still in the early development stage (particularly, relative to livestock feeding) and do not even exist for some crops. Further, many of the more simple crop

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decision aids (e.g., fertilization rates) have tended to be amenable to printed Fact Sheets (although this is becoming less true as groundwater protection issues are more adequately taken into account) while livestock feeding and formulation software utilizes mathematical programming algorithms that are not suited to solution with a $10 calculator and a worksheet.

Adoption Of Computers By New York Dairy Farmers (1987)

Lazarus and Smith (1988) studied 335 participants in a 1986 farm business summary and analysis project conducted by Cornell University. The participants were perceived to be better than average managers because of the nature of the program, and cannot be considered a representative sample of all New York dairy farms. The number of farms with computers used for accounting increased from 1.4% in 1983 to 2.8% in 1984, 4.2% in 1985 and 8.7% in 1986.

Many of the farms had more than one operator. The younger operators with more education tended to be the individuals using the computer. The computer owners had herds that were about 80% larger than the average for the sample, and averaged 5% more milk sold per cow.

The authors also studied paid consultants used by the farmers. Sixty-two percent of the farms retained veterinarians for monthly visits, 81% used tax preparers, 48% used accounting services, 35% used herd management services, and 20% used ration formulation services. Younger farmers with more education were more likely to use three information sources (computer ownership, accounting, and scheduled veterinarian visits).

Computer Ownership By Commercial Ohio Cash Grain Farmers (1987)

Batte et.al. (1988) mailed a survey addressing information usage on commercial cash crop farms to a stratified random sample of 1800 commercial farms. The primary focus of the survey was on information used in making marketing decisions, including the role of microcomputers and software and data bases.

Fifty-three percent of the questionnaires were returned; forty-one percent of the questionnaires were for farmers who were farming and completed the questionnaire. The returned questionnaires which had not been completed were primarily from retired farmers or others who had exited farming, with a small number refused to answer the survey.

The authors further sub-divided their farms to those with at least a hundred acres of grain crops and with no major livestock enterprises; that comprised approximately thirty percent of the acceptable questionnaires. The average farm size for this specialized sub-group was 730 acres. The average age of respondents was 48.8 years, ranging from twenty-five to eighty-three years. Farm experience ranged from six to sixty-five years, with an average of twenty-seven years. Eighty-one percent of the sub-sample had a high school education or less with the balance doing some college degree work. One half of one percent had post graduate work. Forty-three percent had part-time off-farm employment. Twenty-eight percent of the respondents plan to expand, fifty-six percent plan to maintain their current size, while fifteen percent plan to reduce their farm size or exit from farming.

Seventeen percent of the farmers use computers in business management, while eighty-three percent did not. The authors found larger farms tended to rank all information sources higher than smaller farms. Farmers with more formal education placed less value on broadcast media sources than less educated farmers. Farmers who used computers as a management tool placed less value on broadcast sources and more value on professional consultants and periodicals than farmers who did not use computers.

Anecdotal Evidence, Primarily From The Mid-West (1988/89)

A group of eight crop and livestock consultants met in March of 1989 to review the potential of a sample of DSS software for dairy/crop farms (Rotz and Black, 1989). The consultants were from Iowa, Illinois, and Wisconsin. Some of the consultants specialized in dairy cattle management and feeding while others specialized in cropping system management. Education ranged from BS to Ph D. The consultants ranged in age from late 20's to mid 50's. All of the consultants used microcomputers in their businesses; some of the consultants were also software providers and/or provided support services. One of the consultants had been a hardware/software vendor in the early 1980's (CP/M era described in the Indiana study) and had withdrawn from the market because of losses incurred.

As part of the discussion, the participants were asked to estimate the extent of microcomputer ownership in their areas. The estimates were placed in the ten to twenty percent range. They stated use was highest for farmers who were younger and who had more formal education, a result consistent with all previous survey information. Larger farmers were perceived as being more likely to own and use microcomputers.

A second survey was conducted using a small sample of faculty teaching farm management at Purdue (Indiana), Michigan State University, and the University of Minnesota-Minneapolis/St. Paul. They were asked what proportion of the students they had who were planning to return to commercial farms were from farms that either had or were contemplating purchasing a personal computer. The response was forty to fifty percent.

II.C. The structure of agriculture and the economics of microcomputer use

The economic structure of U.S. agriculture is very heterogeneous (OTA, 1986). Farms come in several types ranging from Great Plains farms raising a single crop under a crop/fallow scheme to farms in other regions with complicated rotations involving as many as five crops. Some farms grow annuals such as wheat while others grow perennials such as tree crops. Farm size ranges from part-time operations, where farming is not the principal occupation to one to three family operations where family members provide a significant portion of the labor to large farms where the operator is primarily a manager and most of the labor is purchased. The potential role for microcomputer technology is different in each of these environments as suggested by the Tulare County, California study.[8]

As a context for reference, consider a 600 acre farm in the corn belt raising corn, soybeans, and wheat. That would be a typical one family operation, with supplemental seasonal labor required for planting and harvest. The typical computer that would be recommended for a farm in that size range and complexity would cost $2,500 including printer (AIMS, 1989). The $2,500 estimate for hardware costs does not include monitoring technologies such as weather stations, data loggers, or the capacity to do some of the graphics that would be associated with a Geographic Information System (GIS). They do cover the costs of hardware systems that would permit running most of the software used by farmers today. Perhaps, a modem would be purchased also to facilitate communication with bulletin boards and on-line information services.

A complete line of software is projected at $2,500, although it currently would cost significantly more. The projections of reduced software prices are based upon significant increases in computer ownership and reductions in cost of producing, delivering and servicing software.[9] Both factors will contribute to bringing down the per unit cost of software. The $2,500 projection may be at the lower end of the projections, and reflect only modest integration in a DSS sense. The cost of developing higher quality, more complete (and, complex), and more integrated and database systems will be significantly greater than for much of the currently available software. Training and support costs will also increase. However, the "tools" available to produce software and new concepts in software design are reducing software development and maintenance costs; these factors should partially ameliorate the added costs. A key factor will be whether there will be a large enough increase in the number of users to bring per unit costs down and make systems cost effective.

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[8] Hepp and Olson (1980) point out that the information needs and the form the information is in can be quite different for different sizes of farms. While many technologies, in and of themselves, are size neutral (e.g., most hybrids) the management available to exploit them may be quite different. Hepp and Olson noted that nearly half of Michigan's farmers (Census of Agriculture definition) were part-time. While the percentage of land they farm is much smaller than their numbers, they can significantly impact the landscape and groundwater. Typically, smaller and part-time farmers wanted much more "how to do it" information and less concept and process information than full time and larger farmers.

If we assume that the hardware and software have a five year effective life, the annual ownership cost would be approximately $1,500, or $2.50 per acre. Few new users would buy a complete line of software, complete in the context of the decisions that must be made on their farm. A much more typical approach would be to purchase a word processing package, a spreadsheet (such as Excel, LOTUS 1-2-3, Quattro, Supercalc, or VP Planner), 'decision aid' spreadsheet templates, and two - five "stand alone" programs. Initially, many farmers use their spreadsheets for data base management too. Some of the farmers would purchase a crop records and/or farm records systems. Database management packages (such as DBASE, PARADOX, or RBASE) are purchased too; however, that would be much less common than purchasing a spreadsheet.

Components of a farmer's "1st cut" decision support "system" often include: (1) a field record system which stores and retrieves measurements by field such as soil type, soil nutrient availability tests, pest problems, fertilizers and manure applied, herbicides, insecticides, fungicides, and nematicides applied, hybrids and plant populations used, tillage practices, and yields (and, perhaps, costs) by field; (2) crop management decision aids such as those which recommend fertilizer application rates and timing given soil nutrient availability tests, previous crop, manure applied, method of application, and yield goal[10]; and (3) an accounting system. A stand alone program for projecting financial documents such as cash flow, profit statements and balance sheets might be purchased; also, spreadsheet templates are widely available for that function. This configuration would be typical of the software used by college educated one to three family farm size in the Tulare County, California survey. The introduction of the more intensive decision support activities associated with microcomputer systems typically would increase management and clerical time requirements, not decrease requirements (Harsh and Brook, 1988). That is because few individuals without computers maintain the database or do the level of analysis that is associated with the applications we have described. Thus, the quality of decisions would be projected to improve, but both additional capital and labor would be required to facilitate the improvement. Additional expenditures would also be required for education, service, and such services as telephone time for on-line access and the cost of on-line access.

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[9] Software acquisition prices might look as follows: standard utilities for managing files, recovering files and backing up the hard disk would total $200 to $300; a word processor would be $100 to $250; a spreadsheet and supporting 'add-ins' would be $300 and $500; "decision aid" templates for the spreadsheet would be $100 to $400; an accounting program (general ledger, enterprise accounts, payroll, accounts payable and accounts receivable) would be $500 to $2500 depending upon options (most 600 acre farm systems would be at the lower end of the scale); financial projections (cash flow, profit and loss, and balance sheet) would be $200 to $2,000, crop field records would be $150 to $500, and various stand alone (but, perhaps integrated with the crop field records data base) decision support modules such as fertilizer recommendations, pest assessment and recommendations, land rental and purchase decisions, machinery custom hire vs. lease vs. purchase decisions, and whether or not to participate in the Federal Government acreage reduction or conservation reserve programs could total $200 to $1,500.

The 600 acre farm was chosen as a point of departure because that is a size at which many experts feel the value of the additional decision support exceeds the cost and, particularly for multi-enterprise farms, for which the complexities of the farm operations make it difficult to maintain and manage information in one's head. The size warrants using a computer as contrasted to a calculator, record books, and worksheets. Future informational requirements relative to environmental considerations will increase the need for making more complicated assessments, or acquiring consulting or input supplier services which meet those requirements.[11]

Many smaller and part-time farms may have computers as well, partly justified by non-farm uses. They would also be expected to have less extensive agricultural software and might well have the hardware expenditure of approximately half of what we have budgeted. Larger farms are more likely to have more extensive hardware, particularly including linkages into a more complete decision support system with interfaces to data recording devices, and perhaps more expensive software. However, on a per unit of production basis, the cost may not be significantly larger than it is for the 600 acre reference farm.

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[10] Educational programs conducted by Cooperative Extension Service staff and, to a significant extent private sector providers, have focused upon getting growers to establish realistic yield goals. For example see Beck (1988) and Bundy (1987).

[11] Many input suppliers (e.g., farm supply dealers) and crop consultants are currently using microcomputer models and supporting data bases for making recommendations on fertilizer use and timing and pesticide use decisions to farmers. In many cases, these decisions could be much more fine tuned (and, usually, result in lower fertilizer and chemical input) if better farmer data bases were available (e.g., good weed maps indicating type, scope, and pressure). In some cases, consultants and dealers are providing the monitoring and data base function. This is also true for many IPM services and cooperatives. Other organization alternatives could be used for support of farmers who are too small to support their own decision support systems.

The models and data base structures used by farmers and by input suppliers and consultants are sometimes the same. They differ primarily in how they are integrated and the amount of farm specific information that is available. Typically, one of the greatest challenges is to improve the farm specific data bases.

These annual costs per acre may be placed in the context of cost of production of agricultural commodities. Costs obviously vary considerably by type of farm and by farm size. A point of reference, however, is the average non-land cost of production for cash grain farms with 400 to 800 tillable acres in Michigan in 1988; they were $205 per acre (Hepp, 1988).

II.D. Private and public sector software vendors and on-line data bases

Private sector vendors

Table II.3 gives a partial list of private sector software companies offering principally agricultural software.[12] The table provides a sense of the range of companies and their geographic location.[13] Some of these vendors also sell hardware including turn-key hardware/software systems (e.g., Pioneer Hi-Bred International).

The private software vendors provide a wide range of software including accounting packages (e.g., general ledger, accounts receivable, accounts payable, payroll), crop field and livestock record systems, financial projection and analysis packages, libraries of decision aids including ration formulation, fertilization decisions, irrigation scheduling, and pest management. Also, several agricultural vendors offer programs to assist farmers in pricing commodities, including access to on-line information services. Often, these services may include data which the grower can use in making decisions.

Some of the companies (e.g., Datasphere and FBS) offer software packages designed for use by consultants, bank trust departments, and farm management service bureaus. Some of these packages are used on large commercial farms. The software tends to focus on accounting and financial functions, although there are programs for irrigation scheduling and pest management consultants.

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[12] Many of the vendors listed are members of the Association of Agricultural Computing Companies. AACC sets standards for agricultural software manufacturers and distributors to follow as they develop and market software and computer systems. It also takes on projects too large for individual companies such as market development, consumer (of their products) education and consumer affairs.

[13] This section draws heavily on various issues of Doane's Agricultural Computing and the North Central Computer Institute Newsletter and software data base. Doane's Agricultural Computing serves as a software directory for the members of the Association of Agricultural Computing Companies. It includes both AACC and non-AACC incumber software.

Public sector vendors

Most Land Grant Universities make extensive use of microcomputer programs in their teaching and service activities. Many computer programs are also available through software distribution centers for a modest price; typically, support services are not offered that are comparable to those provided by major vendors.

Examples of the types of software offered include cash flow projection (spreadsheet templates and stand alone computer programs), farm business and financial management transitional planning (four-year, whole farm financial projection for farmers planning to make organizational or investment changes in their farm business), crop field history database management programs, fertilizer and lime recommendations, herbicide selection, sprayer calibration, plant disease diagnosis, IPM applications, irrigation scheduling, crop storage decisions, multiple peril crop insurance purchase decision evaluation, livestock ration evaluation and formulation, livestock productivity indexes, livestock facilities scheduling, land rental and purchase alternatives (in and out), and siting of septic systems. This enumeration is merely representative of available decision support components.[14]

Federal (e.g., Soil Conservation Service/USDA) and state agency's (Departments of Agriculture and Natural Resources) often make extensive use of microcomputer software microcomputer software when working with farmers and on more general problems (e.g., watershed management). SCS/USDA has several microcomputer programs and database management systems that are standard nationally. Some of these are used in evaluating alternatives for meeting the conservation compliance features of the 1985 Food Security Act (a.k.a Farm Bill).

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[14] A directory of agricultural software is maintained by the North Central Computer Institute located at the University of Wisconsin-Madison. In many instances, a larger number of states will have a computer program that has the same objective as a program in a nearby state (e.g., fertilizer recommendations; herbicide recommendations). While some consolidation is taking place, this is the outgrowth of the fact that the soils and crops grown often differ significantly from state to state and that much of the software grew out of concepts, information, and worksheets in printed Fact Sheets that were state specific. Catalogs of available Land Grant University software can be obtained by contacting the College of Agriculture Software Distribution Services in each state. Doane's Agricultural Computing provides a listing of some of the publicly available software, particularly that available from land grant universities.

On-line agricultural services

Table II.4 depicts a list of on-line agricultural services.[15] Many university Cooperative Extension Services, in addition to the ones noted, offer some kind of educational and information services such as the status of pests in various areas of a state. Some State Departments of Agriculture besides those listed may provide information services too, typically in areas such as weather and the status of pests.[16] Also, there are more locally oriented bulletin boards that have not been cited. The principal use of information services at this time is in market information, pricing advice on commodities, and to a lesser extent public domain decision support software available for down loading and data bases on federal and state pesticide regulations and related information.

III. THE DECISION SUPPORT SYSTEM CONCEPT AND MICROCOMPUTER APPLICATIONS FOR SUPPORT OF DECISION MAKING BY FARMERS

The purpose of this section is to develop a more general taxonomy to facilitate seeing computer program as a system, not just as a collection of stand alone computer programs, each independent of the next. This need originates from at least two sources. In the New York survey of farmers cited earlier, farmers stated they did not like duplicative entering of the information, nor the manual entering of the output of one program as input into a second program. Second, and more important, the interdependencies among decisions that must be taken into account. This is particularly true of doing "What if?" scenario studies. Last, farmers need the ability to query their data bases in ways that permit them to better appreciate consequences of previous decisions for future actions. Similarly, farmers need to be able to query data bases that are external to the farm data base for information on both technical parameters (e.g., estimates of how a particular cropping system would be expected to work under their circumstances) and legal restrictions (pesticide label restrictions, best management practices (BMP's), zoning ordinances ...)

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[15] The **NCCI Quarterly**, published by the North Central computer Institute located at the University of Wisconsin-Madison, and **Doane's Agricultural Computing** attempt to maintain up to date listings of software, on-line services and bulletin boards of interest to agriculturalists, including farmers.

[16] These activities have characteristics public policy specialists call 'public goods'; that is, once the information is developed the cost of making it available to everyone is not much higher than the cost of making it available to a single individual.

The section concludes with some examples of DSS that illustrate certain points and/or relate to standard programs that have been enhanced to better deal with groundwater protection. Last, we'll outline general classes of relevant software that are currently available.

IIIA. Concept of decision support systems

The DSS discussion will begin with a standard overview of the decision making process. Next, formal DSS taxonomy will be presented along with examples for illustrative purposes.

Decision making process

Nowak (1988) provides a useful challenge to what he regards as the popular stereotype of the farmer as a passive recipient of information. He says:

> "Contrary to popular belief, the farmer is not an empty sponge anxiously waiting to be filled with valuable insights from ... experts. Instead, information flow to and among farmers is a very competitive, specialized process. Most farmers face a situation of information overload rather than information deprivation. Farmers are bombarded daily ... with information on seeds, fertilizers, pesticides, machinery, livestock, and other farm inputs. In addition, they receive a complex stream of information on management strategies, marketing of products, options available under a multitude of government programs, financial planning, tax planning, and data on trends in agricultural markets. Further, farm and educational organizations send newsletters , notices, and Fact Sheets. Cooperatives and farm supply dealers send out information on the latest pricing information. Farmers are informed about the latest gadgets and 'essential' tools that are supposedly a must for any farm operation. In addition, they receive their share of junk mail and phone solicitations (many classify questionnaires from university researchers, government agencies, and agribusiness firms in this way)."

Further, farmers have very large networks of informal sources of information.

A widely used taxonomy for describing the decision making process (particularly, the desired process) is as follows (e.g., Bransford and Stein, 1984; Harsh, et. al., 1981; Huber, 1980; McCall and Kaplan 1985):

1. Identify problem(s) (**diagnosis**; implies the existence of an earlier goal setting activities);
2. Identify alternatives to solve problems (generate);

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3. Identify and **evaluate** the consequences of the alternatives identified, such as impact on expected net income, risk of failure, labor use, and environmental impacts (e.g., risk of impairing groundwater quality);
4. **Choose** the alternative that best meets the farm family's goals;
5. **Implement** and initiate follow through and **monitoring**;
6. **Review** outcome of the choice and its implementation in order to add to farmer's "knowledge base."

Most management experts find it useful to describe questions as either **strategic** or **tactical**. Strategic decisions are longer-run in nature and infrequently made. They are broad in scope, have longer effects, and deal with the broad selection of means. Examples include buying land, selecting the crop rotation that will be used as a reference point over the next five to ten years, and the broad form of the approach to pest management. Many strategic issues are fuzzy, not well structured, and tend to have less well defined data bases both internal and external to the farm.

Tactical decisions are made very frequently. They are the means for implementing and modifying the strategic game plan. They are more concerned with finding the best specific means to achieve goals, are more concerned with timing, and are much narrower in scope than strategic plans. Examples are form, level and timing of fertilizer application or pest control approach given the strategic plan. Tactical issues tend to be less fuzzy, better structured, and tend to have more well defined data bases both external and internal to the farm. Typically, tactical decision support systems for crop production are designed -- given a strategic plan -- to follow a crop, sequentially, through the season beginning with preparatory tillage and continuing through harvest and marketing. In principal, the question is always "What is the best action to take at this stage of the season, given what has happened so far, and taking into account the consequences of today's decisions and future decisions that must be made?"

Decision support systems: the components

A decision support system must have the capacity to facilitate dealing with both strategic and tactical management questions including the generation of management reports. Figure III.1 provides an overview of the components of a decision support system. The system must have **models** and **databases** to support both strategic and tactical decisions (the right side of Figure III.I).[17] Further, it must have component databases for the farm business including production, marketing, finance, personnel and environmental considerations (the left side of Figure III.1). The center of Figure III.1 depicts the DSS **model** and the DSS **data base management modules.** In a 'full-blown' DSS, for example, there will be a shell that the user (farmer) uses to manage the computer models and associated data bases required to generate the reports, query the data bases, and get assistance for whatever stage of the decision making process in which the farmer is engaged. Currently, there are no DSS with these properties in agriculture which cover most of the decisions that are made on farms; systems are emerging for decisions in a particular area such as weed control.[18]

There are components of DSSs currently available for both the private and public sectors that have many of the characteristics outlined. For example, much of the more complete accounting software is integrated (i.e., general ledger, payroll, accounts receivable, accounts payable, tax preparation). Rudimentary production management DSSs are beginning to evolve where models such as fertilizer and herbicide recommendations call a crop field record system for a description of the soil type of the field (could include components of the Soils 5 record maintained by Soil Conservation Service/United States Department of Agriculture and include additional information on type, soil physical properties, estimates of nutrient levels and pH, and depth to groundwater; conceivably, another data base would have other relevant information on the aquifer). These models are primarily in the prototype stage.

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[17] Alter 1973, 1979; Blackie and Dent 1979; Davis 1974; Emery 1987; Harsh 1987, 1989; Mills, et. al. 1986; Murdick and Munson 1986; Sprague 1980; and Sprague and Carlson 1982 provide overviews of decision support systems and concepts that led to their development. In the corporate world, the concept often (but, not always) is used more narrowly than used in this paper; their focus tends to describe DSS as an outgrowth of the shortcomings of management information systems (MIS). MIS focused upon generating structured reports useful for management questions, but less well suited to less structured questions.

Expert systems (e.g., Carrico et.al. (1989); Harsh, 1988; Hayes-Roth, 1983; Michalski et. al., 1983; Parsyne and Chignell, 1988; Stone et.al., 1986; and Slatter, 1987) and **geographic information systems** (Appendix A) are treated as a subset of decision support systems in this paper. Expert systems are based upon different principles and solution strategies than traditional algorithmic approaches but the objective is generally the same. Thus, while the approach is an important milestone in moving forward in supporting decision making, the critical point here is that they exist and fit in the standard DSS taxonomy.

[18] Readers who have worked with integrated word processor, spreadsheet, and database management computer programs have a "flavor" of the concept. An objective is to be able to move effortlessly around components, including passing information back and forth. The overall program is the "shell" that manages the components.

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There have been at least three drawbacks to the development of these full blown models -- excluding environmental considerations. First, users must be able to enter the system at any point. On one hand, experienced user's want to shortcut many steps. On the other hand, new users only want to use portions of a DSS; they want to "grow into" a system. This is a reasonable design standard, but often difficult to implement. Second, model and data component integration is a significant task and requires a large market to justify the expense of its development. Third, there is not enough standardization across state lines and few companies are large enough to justify the potential development effort to generate an acceptable system. Development may come as more and more prototyping is done, as more standardization occurs, and as enough farmers begin to use computers to warrant a complete system as contrasted to stand alone models or component systems. Thus, the current focus is upon prototyping the concept, developing more and better stand-alone components, and integration on a limited scale.

The retrieval of external information, often in a real-time[19] mode, can be a key component of a full blown DSS. Figure III.2 depicts components that are being prototyped at Michigan State University's Dairy/Crop Farm at the Kellogg Biological Station.[20] These include information that is being electronically gathered from the on-farm weather station, irrigation system measurements, and selected environmental monitoring components to facilitate management of the irrigated crops, including both water and chemical management (chemigation). The information is fed into a database which is called by the irrigation management module. Also, since some of the dairy wastes are in a liquid form, they are incorporated using the irrigation system. That requires information on both the availability and nutrient content of the wastes and other components.[21]

Software designers are moving toward a common strategy in the face of these considerations. The concepts of a model base, database, data collection network, and model and database managers are maintained. Three levels of integration of DS components are considered: (1) stand-alone (typical of most of the 1st and 2nd

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[19] On-the-fly.

[20] The KBS data acquisition network is more extensive and expensive than can be currently justified on economic grounds, but many components are cost effective and others may become economic as more simple approximations evolve.

[21] Maintenance of some of the electronic information gathering devices has been very problematic. Lightening strikes have knocked out components of the system at least once a year since prototyping was initiated.

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generation agricultural software); (2) parent-child structure for some components of a system;[22] and (3) full integration of all (most) components. The move is toward parent-child structures where a parent program (e.g., a crop enterprise budget generator) calls a child program (e.g., fertilizer or pest control recommendations). Both the parent and child programs will accept information from either keyboard entry or from databases such as field record systems or external data bases such as characteristics of products (e.g., water solubility, soil adsorption, volatility, or soil dissipation).

III.B Selected applications that illustrate DSS

Irrigation Scheduling: The Integration Of Groundwater Protection Information

There are a number of irrigation scheduling programs available in both the private sector and the public sector, including services offered by SCS/USDA. These emerged for a number of reasons, including the need for more efficient use of water and energy. The following section describes a prototype irrigation scheduling program in the parent-child structure that is being developed at Michigan State University (Vitosh and Harsh, 1989; Ritchie, 1986). Ritchie also focuses on the level and timing of nitrogen applications. This program includes an index of the potential for nitrogen leaching beyond the root zone.

Tables III.3a and III.3b depict two screens from the computer program for a coarse textured soil in southwestern Michigan. The reference crop is corn. The farmer's tactical management objective is to maintain soil moisture of at least 60% of capacity, the right hand part of Table III.3a. When the grower irrigates, water is added in an attempt to bring the soil moisture content up to 100%. Weather forecasts can be taken into account in making this judgement. The actual percent moisture content is depicted; as well as a graphical representation; "pluses" are used when the soil moisture content is less than 100% whereas "asterisks" are used when more moisture is available than soil moisture capacity.

We see that on June 28 a 2.4 inch rainfall occurred which, given the extent of irrigation on June 26th pushed the soil moisture content over 100% and lead to pushing water (and, potentially nitrogen) below the root zone. That fact is depicted quantitatively under the header drainage and qualitatively under the header nitrogen leaching index of Table III.3b.

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[22] Readers who use IBM and compatible microcomputers will recognize this concept in the form of hierarchical directories.

III.C. Classes of software that are currently available and used in support of US farmer's decisions

Our goal in this section is to place the various microcomputer models in the context of DSS and focus on crop and livestock production models relevant to groundwater quality. First, most models are stand alone with **self-contained databases**, but they are moving toward being more parent-child oriented and model-database oriented. The interest of major regional agricultural cooperatives and private sectors companies will hasten this development if they can maintain viable systems. Note, these focus upon both dealers and farmers with the focus differing among companies.

Second, most Land Grant Universities and many companies have models for making fertilization and pest management decisions; the move is to make these more sensitive to environmental issues (e.g. Beck, 1988; Bird et. al., 1985; Bundy, 1987; Doane Information Services, 1988). A significant challenge for these developers is whether to incorporate explicit risk considerations in models vs. use research models to assist in the development of label guidelines, best management practices, zoning and suggestions for legislation. Many may opt for the latter position, restricting their field models to the scope of well-defined liabilities that the farmer must take into account in decision making.

Third, there are groups taking much more of a whole farm, strategic management approach to the evaluation of farming systems. For example, approximately 30 State Cooperative Extension Services and some lenders participate in the use of the University of Minnesota FINPAK (Hawkins, et. al., 1988) system for evaluation of the impacts of alternative farming systems on profitability and financial position.[23] Ikerd et. al. (1988/89) are extending this approach to take more explicit consideration of environmental consequences; it is a small, but useful start that complements the "stand" alone component models.[24]

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[23] The primary use of FINPAK is in support of Land Grant University educational programs. it is available to the public, but priced such that it's not cost effective except to large volume users. However, FINPAK has been successfully prototyped on individual farms.

[24] The Ikerd/Hawkins (and, associates) approach complements the activities of developers and users of stand-alone and parent-child models. They are developing "enterprise" budgets (e.g., for corn following corn vs. corn following wheat in a Corn-Corn-Soybean-Wheat rotation) which specify the practices which will typically be followed to achieve particular objectives. This approach has the advantage that it builds upon methods widely used in farm management and by lenders.

IV. GROUNDWATER PROTECTION IN AGRICULTURE

The potential for groundwater degradation arises from at least four farm-level operations: livestock rearing, cropping or pasture production, feedstuffs storage and handling; and waste and fuel containment. Cooperation is needed among researchers and extenders of information in the public and private sector, along with appropriate legislative "rules of the game," to develop economically viable management alternatives that protect groundwater quality. The DSS concept provides a systems framework for analyzing alternative farming system design and management alternatives to assess both economic and environmental performance. DSS, including database and model base software, can provide assistance to growers, consultants, input suppliers, public agencies such as the SCS/USDA, and educators in meeting these objectives. Specifically, microcomputers are very useful for calculating formulas (and, more complicated models), interrogating databases, and searching and sorting. Farmers and those who work with farmers have greater capability in these areas than was true a decade ago. Often, however, the issue is one of do we understand what is going on well enough to make the calculations, and, if we can, do we know how to place information in a proper context?

IV.A. An illustrative example

For illustrative purposes, assume that levels of risk associated with groundwater degradation by any substance or compound could be classified[25] as follows:

Class 1. Minimal risk of groundwater degradation (e.g., little chance of any substance or material reaching groundwater

Class 2. Degradation with none to minimal health risk (e.g., addition of phosphorous, sodium, chloride, potassium, magnesium)

Class 3. Degradation with minimal to moderate health risk (e.g., addition of nitrate, natural organic products such as lignin, petroleum products, and some pesticides)

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[25] The risk assessment classifications presented in this paper are hypothetical. Many structures for risk assessment will be developed in the future and are dependent upon the drafting and implementation of groundwater protection laws at the state level and the needs of specific regulatory agencies to develop standards for enforcement and preventive action. An excellent example of the thought behind the development of standards, risk assessments and their relation to groundwater protection laws may be found in Belluck and Anderson (1988). See also Cantor et. al. (1987) for a discussion of what we know about the health effects of agricultural chemicals in the groundwater.

Class 4. Degradation with moderate to high health risks (e.g., addition of viruses, bacteria and some pesticides)

Currently, pesticide use is restricted by federal and state "terms and conditions" appearing on product labels, and allowable BMP's, also described as operating standards[26] (Jackson et al., 1989; Roy, 1989). Most, if not all, State University Cooperative Extension Services provide fact sheets and bulletins that summarize the legal conditions for pesticide use by crop/cropping system.[27] However, in today's dynamic information environment, hard copy bulletins may not be adequate because of the complexity of the rules that determine there effective and safe use. Also, computer data bases maybe required to ensure timely delivery of availability, and labelling information.

Information on pesticide labeling from the pesticide data base and spatial variability from a geographic information system (GIS) component of a DSS could inform a farmer that the pesticide of economic choice is a "Class 4" risk because the chosen field is sandy and the pesticide has high leachability. The DSS could then identify an alternative compound that is effective and less likely to leach, thus environmentally safe, but is ten percent more expensive. This gives the farmer both an environmental and economic basis for making a decision. Geographic information systems, as referred to here, are computer-based information systems having the capability to manipulate and analyze multiple layers of geographic data such as soil type, organic matter content, slope, land use, vegetation, demographics and history in relation to management and planned land use challenges. Further GIS background is given in Appendix A.

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[26] In many states, legislation exists which prohibit use of pesticides in areas in which pesticides appear in the groundwater above minimum standards (conceivably, zero) until such a time as groundwater monitoring no longer detects levels in excess of standards.

[27] For example, in Michigan farmers, input suppliers and consultants can use Michigan State University Cooperative Extension Bulletin, **Weed Control in Michigan**, by J. Kells and K. Renner (1989). The bulletin discusses available herbicides, the "uses" they are labelled for (e.g., crop, soil type, crop's tillage/planting method, method of herbicide application), labelled application rates, and expected efficacy in controlling specific weeds. The Bulletin is updated annually.

Likewise, complementary prototype microcomputer computer programs for corn and soybeans have been developed for Michigan State University's Agricultural Integrated Management Software (AIMS) library that permit the farmer, input supplier, consultant, or CES Agent to identify the herbicides or combination of herbicides that will control the weed types and pressures faced given variables such as crop, previous crop, succeeding crop, soil type, soil ph, tillage/planting system, time and method of herbicide application (preplant, at planting, post plant emergence), and weed pressure by weed. The computer program outputs the list of herbicides that meet these conditions (if any), their cost/acre, and an estimated index of overall control effectiveness. See Renner, et.al. (1989). Many states have, or are, initiating similar activities.

Many private sector firms, including regional agricultural cooperatives are beginning to offer such services to cooperating input suppliers. See, for example, Krause (1988,1989). The major private sector initiatives include linkages with manufacturers and formulators, sometimes resulting in updating of data bases weekly.

King et. al., (1986) and Lybecker et. al., (1984) developed a prototype model that fits the framework described. The model reduces soil-applied herbicides by using weed seed counts to project weed problems rather than prophylactic herbicide application. Nonchemical (mechanical) as well as chemical weed control options are included. Although driven by economics, trade-offs in terms of higher weed populations, potentially lower herbicide loading, and profit differentials are identified for farmer selection.

A DSS-based risk assessment can also help farmers choose between alternative activities. For example, a dairy or hog farmer might be faced with the choice between using scarce time and tractor power to empty nearly full dairy or swine waste storage lagoons vs. cultivating a field where weeds have a good start. According to weather forecasts, rain is expected by the time one of the two operations is completed. The DSS analysis indicates a potential groundwater problem from either operation. If the field isn't cultivated to control the weeds before the rain prohibits field entry and promotes further weed growth, it will require later treatment with a leachable herbicide identified above as a Class 4 risk for groundwater degradation. However, if lagoon waste is spread and rainfall is substantial, significant amounts of nitrogen (as nitrate) may leach below the root zone and probably to groundwater resulting in a Class 2 risk for degradation.[28] If the waste is not spread, lagoons may overflow, also resulting in a class 2 risk. Other factors being equal, the farmer may choose to cultivate immediately rather than spread lagoon waste, since this will negate the need for later herbicide application with its relatively higher risk to groundwater.

The best management practices (BMPs) approach to decision making goes beyond the singular criterion of labeling guidelines to look at systems of crops, cultural practices, and waste management schemes that are acceptable given soil type and other relevant factors. Some BMPs are currently a prerequisite for participation in federal farm programs (e.g., 1985 Food Security Act), and are relatively amenable to evaluation in a DSS environment. In many states, Cooperative Extension Services and consulting groups are placing alternative management systems in a "whole farm" perspective, with implications for labor scheduling, financing and management and quality control skill requirement. For DSS applications to be fruitful in this environment, information must be organized in a form relevant to microcomputer-based operations.

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[28] The output might be similar to the irrigation example in Part III.

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IV.B. CURRENT CAPABILITIES OF DECISION SUPPORT SYSTEMS

Initial attempts to create DSS as large "shells" into which generalized software "options" programs could be incorporated have not been very successful. Long development time, high cost, and lack of farm level specificity have worked against their adoption. The global approach has been largely replaced by a series of stand-alone, farm level software modules designed to assist in specific decisions, some potentially related to groundwater quality. Examples include fertilizer recommendations, manure management, irrigation and nitrogen application scheduling, crop production and perennial crop "when to reseed" modules and various pest control and integrated pest management aids. A strong future of such modules is that they force farmers to reach decisions in a logical step-wise fashion and provide automatic prompting to make certain all pertinent data and factors are considered.

Major factors limiting DSS use today are the small number of farms that have computer capabilities, and the challenge of training farmers who have computers to use them for decision support. Though computer, communication, and data collection (e.g., weather station, scales) hardware technology has progressed, lack of **hardware standardization** impedes widespread use of DSS software at the farm level linking to electronic data collection equipment. Most current DSS modules have little database capability (usually incorporated as part of the stand alone program), require a knowledge that may be difficult to assemble in a timely manner (e.g., the nitrogen content of manure), require more keyboarding than most farmers like, and are almost always being upgraded by the developer to provide additional information, prompts or dimensions. Keeping the prior purchaser abreast of these developments poses a real challenge.

DSS approaches to the management of pesticides and other organic compounds with clearly associated health risks are in their infancy and development efforts will focus on this area for some time to come. With present DSS approaches structured around label and BMP requirements, (i.e., where label or BMP compliance dictates the decision), farmers are reluctant to take responsibility for problems created when approved directions are followed. **Current DSS capabilities are constrained by a lack of detailed, verified models of water flow through soil and geologic formations down to groundwater, of the leachability of various pesticides and nutrients in different soils, climatic conditions and production systems** (e.g., see Figure IV.2 depicting fate of

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organic chemicals).[29] The development of these models, along with the challenge of constructing DSS modules that can accommodate the spatial variability of landscapes, even single fields, in the form of an individual farm GIS, will provide a strong framework within which complex groundwater quality decisions, data verification and modelling will take place.[30]

Farm-level DSS currently lack databases and software that prioritize groundwater protection. The demand for groundwater protection has come from society as a whole, and from farmers themselves, as they better recognize risks and public concern about contamination[31].

Presently, most decision support systems are based on economic rather than environmental factors, but exceptions are emerging. Computer models under development in Florida, Georgia, and California (Bailey, 1985; Carsel, 1984; Holden, 1986; Jenkins, 1989; Schwartz, 1988) predict the leachability and other properties of pesticides, although they do not include a nutrient component. Development of nutrient components in models is imperative, given the known degradation of groundwater from nitrate leaching, and possible resultant health hazards.

An expert system under development in Massachusetts (Jenkins, 1989) will predict leaching risks of many pesticides in different soils. A crop recommendation guide that will serve as an introduction to this system for potential users, will include a component for protecting groundwater from pesticide contamination. Once the database is developed and the system is in place, development of a nutrient component is planned. Such expert systems will be important in providing advice to farmers. With the development of integrated, whole farm DSS, expert system information will possibly become building blocks for decisions based upon integration of whole system considerations.

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[29] Environmental consultants with geological, biological, and engineering training are emerging who specialize in water quality issues, including groundwater data management systems for monitoring and permitting wells, predicting conditions under which hydrocarbons may be generated, predicting the spread of a toxic solution (e.g., land 'treatment' site, lagoons), water quality sampling protocol, mapping and plotting of landscapes and aquifers, and projecting groundwater flow streamlines.

See, also, Anderson and Robert (1988) and Beck (1988) for discussions of "Soil Information Systems." In our terminology, the soil information system would be a database file that would be tapped by production management models. These systems are in the prototype stage relative to integrated DS systems; however, many systems of this type are very useful in support of consulting support to farmers. They permit access and provision of very detailed site specific information in a cost effective manner. Much of the current need is to "clean up" the information in these databases; much of this will occur during applications as users raise questions.

[30] To be networked into a larger GIS on a township, watershed, aquifer or perhaps county basis.

[31] As Senator Wyche Fowler (D-GA) has stated, "They (farmers) don't want their own families to drink from contaminated wells. They don't want to ship food to market that threatened the health of American consumers. They want to know how they can address these problems without compromising their livelihood." (Fowler, W., 6/89). Sound federal and state regulations, incentive programs and DSS programs which provide suggestions for alternative practices and data verification will help protect that livelihood.

IV.C. The Near Future

As recognition of the need for sustainable agricultural methods grows, developers of DSS will begin to incorporate an environmental dimension into stand alone modules for irrigation scheduling and for managing nutrients from fertilizers, livestock manure, crop residues, legumes and other sources. According to the Experiment Station committee on Policy (ESCOP) Subcommittee on Computer-Aided Agricultural Decision-Support Systems (CAADSS), coordination has been provided for research and development efforts required to implement a national computer-aided agricultural decision-support system. The CAADSS will utilize national, regional and local services of the USDA-Agricultural Research Service, USDA-Cooperative States Research Service and USDA-Cooperative Extension Service. Fundamental to that system is an environmental component.[32] There will also be an effort to integrate existing and evolving modules into a database system that can cross-link information from several sources. For example, a field record system may combine past year yield and fertilizer application data with current year soil test results to create a fertilization strategy for the current growing season.

Cycling of nitrogen, phosphorous and other nutrients in the agricultural landscape may become well enough understood to enable prescription nutrient application. Data on individual farms could be incorporated into the geographic information systems component of DSS, allowing farmers to precisely plan and manage nutrients for maximum economic return and groundwater protection. Well-developed DSS programs for nutrient management should be in operation within three to ten years. These programs will incorporate such items as nitrogen release rates from manure application, cover crops, legumes, and commercial fertilizers.

The use of DSS database and inventory control software, linked with disposal alternatives and policy incentives to recycle, can significantly reduce contamination from fuel and oils. On the other hand, the use of all types of synthetic and natural organic pesticides will likely continue to pose a challenge. The mentality of "I have a weed or bug. What can I use to kill it?" will be slow to change. Only toward the middle to end of the next decade may emphasis swing toward DSS approaches with stronger ecological bases. The tremendous diversity of compounds already in use and the need for a database on groundwater contaminants to support regulatory action make it difficult to use an ecologically based approach now. It will be several years before the database will be sufficient to improve labeling to reflect groundwater quality threats by a wide range of pesticides and other compounds, or before strategic cropping systems are developed for nonchemical control.

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[32] Paper by Don Holt, CAADSS Subcommittee Chairman, September 27, 1988.

IV.D Beyond The Year 2000

The first decade of the twenty-first century will see greater computer capabilities at the farm level and substantial advances in the use, analysis, and reliability of electronically collected data. (Many remote sensing and electronic data capture technologies already exist but many devices are presently physically cumbersome or cost-prohibitive.) Database decision support systems may begin to be maintained and serviced by off-farm professionals as farmers gain confidence in the technology.

There will still be modular, stand-alone DSS on farms; but these may well serve more and more as local stations for organizing, screening, transmitting and receiving data and information to and from a larger DSS base for interpretation and organization. Farmer use of commercial databases and DSS for farm operations will grow, much as the use of professional tax services has, with regulation, accountability, and legal liability playing key roles. For example, today soil and well water samples can be collected by the farmer or a commercial firm and analyzed in an off-farm laboratory; the results, interpretations, and recommendations can be electronically transmitted to the farm's database. In ten to twenty years, those results may be handled by independent consultants who specialize in assuring compliance. As a result of technologies and models now beginning to emerge, it may become possible to limit groundwater problems and still see an array of economically viable agricultural enterprises on the landscape.

Biotechnology may provide new, more nutrient-efficient plant cultivars while innovative ways of managing nutrients could be suggested by decision support systems directed as much at the demand for quality, contaminant-free food and feed as at groundwater protection. Management systems based on the ecological principles necessary for the development of a sustainable agriculture may eliminate the use of toxic organic compounds. Possibly, decision support models emerging in this climate may project how well a crop will grow in competition with various weed or insect populations and propose nonchemical control alternatives.

Decision support management tools for livestock wastes, fuels, and other compounds that have the potential to degrade groundwater will have been developed and will begin to be adopted, monitored and regulated within this 20 year period. Farm-level databases will be based on inventory control or handled as a part of nutrient loading and management models.

Ultimately, DSS must predict the consequences for groundwater quality of any action on or inputs to the agricultural landscape. Databases could provide information to a GIS which could model water flow through the entire hydrologic cycle, describing its flow and location at any given time on a field, whole farm, watershed or aquifer basis, and predict the nature and amount of contaminants entering the cycle at any given point. That system could present the farmer with an array of management alternatives and their potential economic and environmental consequences in the form of a probability or risk profile, with the intent of providing methods of intercepting or truncating groundwater degradation instead of simply inventorying consequences. This could be projected for any area over an appropriate period. Management practices and options could be generated with an interactive program component and the aid of expert systems.

IV.E. Monitoring Systems Of The Future

Ultimately, remote sensing devices could be linked to on-farm monitoring systems to continuously measure key operational parameters with a potential impact on groundwater quality. Technology already exists in the areas of GIS, remote sensing, and dynamic geo-referencing by which nozzle delivery rates on agricultural sprayers for pesticide application can be varied electronically based on soil type and field coordinates (Lusch, D., 1989). In the future, if economics permit, specific information could be fed to an on-board, computer-based GIS giving soil type, slope and other physical properties. A tracking device on the tractor could bounce signals off a satellite with civilian frequencies and the tractors' position in the field could be known in three dimensions, at any time, within centimeters (dynamic geo-referencing). Spray delivery rates could be automatically adjusted: lower rates for sandy soils, bare ground or steep slope; higher rates for heavier soils, level ground or the existence of a crop to intercept spray. This technology exists but is presently cumbersome and cost-prohibitive.

Transponders now used on some farms (e.g., KBS Dairy; see Battelle, 1985a, b) to identify and record data on livestock as they enter a milking parlor or a scale, might be upgraded to reveal where particular animals are located in exercise lots, grazing pastures, or barns. By sending these data to a GIS, projections could be made by a DSS of the natural distribution of animal waste over the landscape, and of the potential vulnerability of underlying aquifers to nitrates. The DSS could then plot trajectories so that liquid manure applications do not overlap areas where wastes are concentrated.

Remote sensing devices as varied as satellites or tethered balloons with scanners could provide a fairly continuous read-out of crop quality, moisture and nutritional stress, and other data useful for scheduling irrigation, nutrient and pesticide applications. Some of the information obtained at farm level could be utilized on a regional basis, for example, to assess the implications of an alfalfa weevil outbreak first detected by one or more scanners. DSS models could provide probable paths of expansion of the outbreak and suggest possible treatments, the implications of delaying treatment, and probable risks to the environment as a result of the treatment.

Remote sensing and electronic data transfer could provide input to GIS weed population and vegetation maps throughout the growing season. These distributions could be fed to DSS models designed to project how well a given crop will compete for water and nutrients in a particular field. Yield decreases associated with weed competition might be avoided, even if no herbicides are applied, by carefully scheduling planting and irrigation to give the crop a competitive edge over weeds. Such manipulations may, in fact, be more effective than herbicides.

Remote sensing devices could also be used to determine the moisture stress of a cover crop to help the farmer decide when to turn that crop under and plant a cash crop (e.g., before soil moisture necessary for cash crop growth is too depleted by the cover crop). On the other hand, if a reasonably heavy application of manure nitrogen is being trapped by the cover crop and there is ample soil moisture, the growing season for the cover crop might be extended to trap more nitrogen and to reduce the amount of nitrate leaching in the event of a heavy rain. Such a determination could be made directly with input to DSS models from neutron probes in the ground.

V. EXAMPLE OF THE INTEGRATED DSS AT KELLOGG BIOLOGICAL STATION

The Dairy/Crop Farm at Michigan State University's W. K. Kellogg Biological Station (KBS), (see Figure V.1) is presented as a case illustration of the process of incorporating an integrated decision support system (IDSS) for use in farm management. The Dairy/Crop Farm is a state-of-the-art research, development, demonstration and education facility. While it is not a commercial farm in the strictest sense (due to research, demonstration and education constraints and, additional labor is needed and funded by Michigan State University), the farm land base is used to support the dairy herd and 75% of the operating budget is generated by dairy and farm production. It is that component of farm operations which has supplied incentive for the development and use of existing stand-alone software modules and set the goal of whole-farm integration for the evolving DSS prototype. IDSS has progressed on several fronts on the farm, though it is far from the goal of a totally integrated prototype. Though many definitions and levels of decision support systems may exist, DSS as defined by the KBS prototype will be a total integration of electronic data collection, remote sensing, geographic information system, computer simulation model, expert system and artificial intelligence technologies; each technology capable of standing alone but more importantly capable of being a component in a synergistic integration into a decision support system.

Currently at KBS, some data acquisition is automated and inputed directly to the computer system in the main office. For instance, in the milking parlor, identification transponders on each animal along with strategically placed sensors allow monitoring of milk production, weight, movement and other functions on an individual animal basis. This inventory system is used to support various decisions with regard to herd health problems and culling. Data logging devices that work off the transponders' frequency will automatically record treatment activities by individual animal, for example, injection of bovine somatotropin hormone which increases milk production. This record, added to the computer database, could be related to the cow's body condition over time, to indicate whether ration changes are required to maintain the animal's health and sustain elevated milk production. In the near future, data will be automatically collected on temperature and humidity in the barn and milking parlour.

Within a year, automated metering devices will monitor livestock water consumption within the barn, and water use for the automatic barn flushing system. (For an explanation of the flushing system and manure handling at KBS, see appendix B.) These data will go into databases for nitrogen and irrigation scheduling. As it evolves, this component of the DSS program will help the farm manager decide, for example, whether to recycle more water for barn flushing (after liquid-solid separation), or switch from flushing to scraping temporarily, to avoid water use.

Harvested feed is weighed, and put into bins or silos. Weight and storage location are recorded along with field source, and on a limited basis, feed quality determinations, in the DSS database. Feed rations are then electronically mixed in the feed center.

Feed wagons carry formulated rations from the center to specific groups of cows designated as either high or low producers, three-times-a-day milkers, or two-times-a-day milkers. Truck scales automatically record the weight of feed delivered to each group and provide data used later in milk production and waste handling decisions.

Irrigation scheduling programs use current and stored weather station information and factors related to crop growth to recommend timing, rate and frequency of applications. Soon options to allow a more prescribed application, and placement of nitrogen and other chemicals through the irrigation system will be incorporated.

Neutron probes in the fields are attached to data loggers for entering current soil moisture data into the computer. These prototypes are reducing reliance on weather station data. Within three to five years, spatial data on soil moisture and nitrate content of soil water (as measured with suction lysimeters) will be linked to DSS and GIS software to support decisions on irrigation and chemical additions to subsets of fields. A grant has been received and work is progressing in the development of a station-wide GIS, which will be based on the stations' mainframe computer. Each unit at KBS (e.g., the Dairy, small plot research area, the Kellogg Forest, or laboratory based faculty and technicians) will be able to access the GIS from unit offices.

Integrated pest management data are presently obtained by IPM scouts, entered into the database and provided to the farm manager in the form of computer printed pest bulletins. Soon, data will automatically be entered into the computer base and graphically displayed when the IPM scout returns from the field. The farm manager will be able to overlay these visual images on the GIS grid and relate them to data bases on soil type, cropping and irrigation patterns, water and chemical applications, cropping plans or other information that contributes to better management decisions.

Maps of soils in various stages of drying after a rain would reveal patterns of water retention. Patterns of insect outbreaks and weed spread could be recorded over a single season or over many seasons, and changes noted, to allow more precise management strategies. Many IPM activities now focus on insect counts and damage assessment, not on the origins of outbreaks. Knowing that an old field or nearby orchard is the wintering location of a particular insect can help focus and reduce pesticide use, and thus protect groundwater resources. GIS and DSS at KBS will provide that data.

The emphasis at KBS is on managing nutrients, pesticides and other inputs such that they do not escape the root zone. Ideally, they are either captured by the crop or by microorganisms, inactivated by the soil or some other mechanism, or degraded (see Figure V.2). Thus, it is important to schedule and apply additives according to crop growth and nutrient needs. This requires careful measurements of plant nutrient uptake and of nutrient levels in the soil profile.

Monitoring of nitrate or pesticide levels in well water is carried out to support long term impact assessments of surface activities, and to provide specific decision making information. All 22 household, irrigation and other wells at KBS have been sampled and analyzed for nitrate levels. At least one hundred wells bordering KBS property (upstream and downstream in terms of groundwater flow) have been sampled for comparisons. These data will be entered into the database and updated annually. Similar information on key pesticides will be obtained on the property and added to the database. In addition, a lake adjacent to the dairy, waste lagoons, monitoring wells under the lagoons, and sample wells in a grassed waterway leading from the farm headquarters toward the lake have been monitored to assess seasonal and year-to-year impacts of the livestock operation.

GIS data bases will contain farm-scale histories of cropping, manure and fertilizer application, and future plans and yield goals for the farm. Drawing on the historical database, the DSS will determine BMPs for nitrogen application, with and without manure application, and suggest management options based on both economics and groundwater protection.

DSS software will be used for better management of liquid and solid manure. Regular analysis of liquid application by volume and composition will be put into the database. When liquid waste is applied through irrigation, its application will be spatially tracked through GIS linked software. Eventually the GIS capability will allow precision applications of manures, fertilizers and chemicals, based on a number of factors that call for spatial variability data. The GIS database will allow tracking and graphic display of past spatial variations in landscape management activities, to help choose future DSS generated alternatives. The consequences of decisions can be projected in time as well as space with GIS technology. Superimposing projected crop sequences on a GIS base, for example, will enable a farmer to make improved nutrient, pest management, and operational decisions.

Remote sensing capabilities now being developed at KBS will add information to GIS and DSS databases on moisture-nutrient-and pest-related plant stresses. Most farm-scale remote sensing is now accomplished by contract aircraft on a fly over basis. To support DSS database activity, the use of spectral scanning and dynamic geo-referencing and other technologies will become necessary. Use of these technologies for individual farm decisions is some time away, however, and the service sector rather than the individual farmer may collect the information.

VI. FUTURE DIRECTIONS AND POLICY OPTIONS

The development of consistent federal, state and local policy is necessary for groundwater protection. The federal government has delegated much of the responsibility for groundwater to individual states where the focus is on prevention and education rather than remediation. The high cost of remediation and lack of remedial methods presently necessitate the emphasis and prevention and education.

At the federal level, no standards have been set with regard to contamination of groundwater by agricultural sources. However, the 1990 farm bill will address the topic of groundwater protection and the next logical step for the Clean Water Act (up for reauthorization in 1991) seems to be an inclusion of national goals for groundwater. Also, President Bush has stated his commitment to Congress to:

- Protect groundwater without infringing upon farm practices.
- Support water quality programs which abate pesticide use.
- Challenge farmers to be ultimately responsible for changing farm practices to protect the groundwater.[33]

While many states struggle with cogent and enforceable definitions of "non-degradation" some have moved forward with the enactment of groundwater protection legislation based upon various means, from the use of maximum contamination level guidelines (MCL's) to the development of state land use plans. Point source contamination of groundwater is more easily addressed than non-point source because monitoring becomes more difficult and the source less identifiable. This is the case in agricultures contribution to contamination.

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[33] John Blodgett, Assistant Chief, Environment and Natural Resource Policy Division, Congressional Research Service, Washington, D.C. and Velma Smith, Director, Groundwater Project, Environmental Policy Institute, Washington, D.C. presentation at the "Midwest Groundwater Quality Protection Challenge," St. Charles, IL. November 1-3, 1989.

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Many agricultural practices lead to contamination of groundwater: nitrates from manures and crop residues, organic contaminants from pesticides, etc. State legislatures believe one method of addressing the contamination resulting from farm practices is the institution of best management practices (BMP). Flexible incentive programs are needed to attract farm participation in adherence to BMPs. If voluntary efforts are not made, it is feared that BMPs may become mandatory.[34]

Oregon has organized a strategic water management group to develop a state wide land use plan. Minnesota has forged ahead with plans to take land out of agricultural production where there is imminent danger of pesticide contamination. Idaho has prepared a groundwater plan to be implemented by state agencies. Again, many states are pursuing legislation alternatives, based upon the tenant of education and prevention and not remediation. As monitoring, sampling, and modelling capacity improves, non-point sources of rural groundwater pollution will be addressed under rules similar to those governing point sources.

The present flurry of activity to gather groundwater information could result in a backlash at the farm level. Fear of potential legal liability and potential punitive action could induce farmers to refuse access to their land for monitoring and sampling. A national survey has indicated the more pesticides a farmer uses, the stronger that farmer opposes regulation and restriction of pesticide use. Farmers do recognize that problems with groundwater contamination exist and 60% have indicated they would use free technical assistance to reduce fertilizer and chemical use. The question then becomes one of enforceable regulations, at what level those regulations are to be enforced and the advent of peer pressure to protect common aquifers.[35]

Regulatory and permit action should evolve at the farm level to insure that equivalent rules and regulations apply to all farmers. Those who manage on the basis of maximum yield, with no regard for the environment, can put a number of good managers out of business by polluting a shared aquifer (common property resource problems). Regulations will be as necessary for the protection of environmentally sound farming enterprises as they are for groundwater protection in general. DSS supported management decisions and independent verification of the effectiveness of DSS supported practices can help protect environmentally sound farming enterprises from nuisance or class action lawsuits as well as unfounded or generalized regulatory action.

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[34] Larry Moranai, National Conference of State Legislatures, Denver, CO. Presentation to the "Midwest Groundwater Quality Protection Challenge," St. Charles, IL., November 1-3, 1989.

[35] Dixon Esseks, Center for Governmental Studies, Northern Illinois University, DeKalb, Illinois. Presented at the "Midwest Groundwater Quality protection Challenge," St. Charles, IL., November 1-3, 1989.

Future policy decisions and regulatory actions will likely require extensive computer-based data sets, maintained by governmental agencies or private contractors, and electronically accessible to individual farmers and those who work with farmers. Extensive baseline data on groundwater quality are needed at the onset. Depending on the groundwater policy adopted, the appropriate agency(ies) would be given permitting, monitoring and regulatory responsibility. As data bases grow and regulations, on a statewide and local basis, become more extensive, standards must be set for specific parameters. Data digitization for aquifer locations, slope specifications and common indicators of soil type, crop varieties and other variables must be standardized. Policy at the sate level must set those standards (e.g., location data that adheres to the State Plane Coordinate System in Michigan).

Policy must also set forth management structures for the cooperation of state agencies charged with monitoring, education and remediation activities to ensure accessibility from agency based information systems or DSS to statewide databases, e.g., the statewide groundwater data base (SBDB) or the Michigan Resource Information Survey (MIRIS), and the exchange of information between agencies and the private sector. Most importantly, federal and state legislatures must set policy on the appropriation of funds for the development of data bases, government agency DSS, education programs and research to deal with the groundwater issue. Limits on contributions to groundwater quality degradation will need to be established, and arrays of acceptable enterprise and management practices defined. Using DSS tools, the farmer can then aggregate various management systems that are environmentally safe into whole-farm operational protocols.

An array of technological tools will be available to verify the effectiveness of the farm management plan, ranging from simple inventory controls to dye marking of pesticide/fertilizer applications on an individual farm basis for intensive chemical tracking. These kinds of tools, linked with electronic detection, identification and data collection devices, offer the opportunity for legal and regulatory protection of groundwater and the farm enterprise alike. To achieve these goals, extensive DSS developments are needed at the farm, consultant and institutional levels. The private sector may be much better organized to police itself than various government agencies. For example, portable analytical capabilities could be used by private licensed and bonded consultants to verify the effectiveness of many practices. It is possible to construct DSS based institutional capabilities to provide such service at a reasonable cost.

APPENDIX A. Geographic Information Systems (GIS)

Spatial variability is a real challenge in farm level management; one that demands creativity and skill in the tactical decision making of individual farm managers. Decision support systems, with input from a Geographical Information System (GIS) component, will greatly augment the farm manager's ability to make informed decisions with regard to such problems as soil type, its variability across the landscape and its effect upon the movement of pesticides, nitrates, fuels and other toxic compounds into the groundwater.

GIS has been defined (Dulker, et al., 1989) as "...a system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth," which may be as small as a land parcel, (e.g., a suburban lot, stand of trees or farm field), or as large as the earth (Carter, 1988). As with all computer-based information systems, a major advantage is the GIS capacity to simultaneously consider many levels of information. As Parker (1988) has indicated, the human memory may register two or three layers of information at one time, but the challenges of spatial data may require manipulation and analysis of dozens of layers. A GIS can work with as many layers as computer hardware will allow.

GIS is not a futuristic concept; it is a technology presently available and used by all types of planning and resource management agencies, at all levels of government (Spectrum, 1989). GIS can provide timely, problem-specific, spatial information which fosters and enhances the decision making process; expanding opportunities for reducing the cost of critical decision-support activity.

A relevant example may be the necessity to make a decision whether an application of lagoon waste to a particular field is possible and at what level of risk for groundwater degradation. A farmer has recognized the imminent need to empty an animal waste lagoon and needs to make a decision whether it is possible to apply it to any of the farm fields. Accessing the GIS will provide an ability to simultaneously consider such important factors as shown in Figure A.1:

Overlay one - Water: the proximity of a given field to any surface water (river, lake, pond) and relative position to the groundwater aquifer.

Overlay two - Soils: soil type and organic matter content--affecting the leachability of waste nutrient components; soil slope--affecting waste run-off, which may dictate application rate and method. Subsurface geology, aquifer data, etc.

Overlay three - Land cover: existence and type of cover crop or cash crop; growth stage, etc. Does the capability exist for up-take of nutrients supplied by the manure? This affects the decision whether to apply any waste at all and the rate at which it is applied.

Overlay four - Boundaries: field location may indicate a proximity to residences. Given indications of a prevailing wind, a decision may rely upon whether odor could become a problem.

Overlay five - Land use: pasture, cash cropping, fallow; implications of waste application to each.

This information, used in conjunction with an analysis of manure nutrient content could serve as input to an expert system on animal waste management which could then predict the risk involved in manure application with regard to phosphorus contamination of surface water and nitrate contamination of groundwater. As Parker (1988) aptly puts it, the most important aspect of GIS, and other DSS for that matter, may be that "Mistakes made in computer simulation are much less painful and expensive than mistakes made on the ground."

Possibilities for the integration of GIS components into much larger DSS are evident in examples throughout the body of this paper. Suggested uses are innumerable and as varied as the creativity of potential users. As GIS becomes more refined and remote sensing technologies become more economical they will become integral parts of much larger integrated DSS linked to common databases, to be accessed by individual farm managers, private consultants, institutions and regulatory agencies.

APPENDIX B Dairy Barn Flush Cleaning System and Manure Management at KBS

Slurry from the manure flush system operating in the barn and milking parlour is fed through a liquid-solid separator in the waste-handling building. The solid component is composted and used as livestock bedding or mulch, while the liquid is recycled for further barn flushing or is shunted to storage lagoons and subsequently applied to crops.

Solid manure and bedding is scraped from the stalls when cold weather makes the flusher system inoperative, and is always scraped from the heifer and maternity barns, calf hutches and exercise lots. Several manure products are land-applied.

Composted solids used as livestock bedding and mulch are generally low in easily decomposable nitrogen compounds. Record keeping and inventory control will be the focus of decision support systems related to them. These applications will incorporate data on the amount produced, its moisture, nitrogen and other nutrient content, required time for composting to a safe temperature, and location of application (with regard to previous nitrogen loading).

Liquid manure and slurries from holding lagoons and tanks are applied in many ways: via surface unloading from a tractor-drawn tank, and various injection and irrigation systems. In all cases, the composition, amount and distribution of manure nitrogen must be carefully monitored, along with the volume of liquid applied.

The level of nitrogen applied through the center pivot irrigation system is often quite low, and this system serves mainly to transfer water from lagoons to crops. In arid to semi-arid regions, application is based on crop water needs. However, in many humid to semi-arid regions such as KBS, use of the system is based on the need to transfer water from full lagoons to a small land base. Even if the total nitrogen needs of a crop are not exceeded, management of the application to coincide with a crop's maximum capacity for uptake becomes a real challenge. Application of too much water with low nitrogen content may result in nitrate leaving the root zone before the crop can utilize it. Nonetheless, the decision to apply may be weighted heavily by the need to empty storage ponds to prevent overflow into lakes or streams.

Table II.1 Applications in 1986 by Tulare County California Farmers Who Own Computers[1]

Application	Percent
Accounting (e.g., general ledger and cost accounting)	75
Spreadsheet (e.g., LOTUS 1-2-3)	59
Payroll	67
Production control	22
Database management (e.g., DBASE, PARADOX)	30
Production management decision aids	17
Crop/livestock management	9

[1] Farm types included field crops, vegetable crops, tree crops, grapes, nursery, dairy, beef, and other livestock. Related businesses associated with the farm included packing sheds, other sales, farm management consulting, pest management advice, and other services.

Table II.2 Probability of Spreadsheet, Accounting, and Production Decision Aid Uses in 1986 for a 41- to 5 Year-Old Farmer with No Farm-Related Business in Tulare County, CA.[1]

Gross Revenue	Trees	Grapes	Field Crops	Trees and Grapes	Dairy and Field Crops	Trees and Field Crops
			Spreadsheet Use			
($)						
			High School Education			
100,000	0.07	0.05	0.04	0.11*	0.04	0.09
500,000	0.08	0.05	0.05	0.12*	0.04	0.10*
1,000,000	0.08	0.05	0.05	0.13*	0.04	0.11*
4,000,000	0.02	0.01	0.02	0.04	0.01	0.05
			College Education			
100,000	0.28*	0.23*	0.19*	0.35**	0.16*	0.29*
500,000	0.31**	0.24*	0.21**	0.39**	0.18*	0.34**
1,000,000	0.31**	0.24*	0.22**	0.42**	0.20*	0.38**
4,000,000	0.07	0.05	0.06	0.13*	0.06	0.15*
			Accounting Use			
			High School Education			
100,000	0.06	0.03	0.03	0.12*	0.00	0.09
500,000	0.12*	0.08	0.06	0.19*	0.01	0.15*
1,000,000	0.22*	0.17*	0.13*	0.28*	0.04	0.22*
4,000,000	0.73****	0.70****	0.62***	0.77****	0.57****	0.71**
			College Education			
100,000	0.14*	0.08	0.07	0.31**	0.01	0.26*
500,000	0.28*	0.19*	0.16*	0.44**	0.03	0.37**
1,000,000	0.46**	0.37**	0.32**	0.57***	0.09	0.50**
4,000,000	0.91****	0.89****	0.86****	0.93****	0.82****	0.90**
			Production Decision Aid Use			
			High School Education			
100,000	0.004	0.000	0.001	0.002	0.023	0.008
500,000	0.007	0.000	0.002	0.002	0.037	0.012
1,000,000	0.012	0.001	0.004	0.004	0.061	0.021
4,000,000	0.099	0.007	0.044	0.034	0.408**	0.174*
			College Education			
100,000	0.031	0.002	0.011	0.011	0.126*	0.054
500,000	0.045	0.003	0.017	0.016	0.178*	0.079
1,000,000	0.068	0.005	0.027	0.024	0.256*	0.118*
4,000,000	0.280*	0.027	0.154*	0.108*	0.727****	0.434*

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[1] * depicts probability is between 0.10 and 0.299 (10 to 39.9 percent)
** depicts probability is between 0.30 and 0.499 (30 to 49.9 percent)
*** depicts probability is between 0.50 and 0.699 (50 to 69.9 percent)
**** depicts probability of 0.70 or greater (70 percent or greater)

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Table II.3 Private Sector Software Companies Providing Agricultural Software[36]

AB Consulting Co., Inc.
Lincoln, NE

ABC Systems, Inc.
Western, NE

Ag Computer MKT
Tuscola, IL

AG PLUS Software
Ida Grove, IA

Agpro Software, Inc.
Phelpston, Ontario L0L 2PO Canada

Agribusiness Computer Strategies
Glastonbury, CT

Agri-Com Systems, Inc.
Chambersburg, PA

Agricultural Software Consultants, Inc.
Kingsville, TX

AGRI data
Latham, NY

AgriData Resources, Inc.
Milwaukee, WI

Agri-Data Systems, Inc.
Phoenix, AZ

Agri-Education, Inc.
Stratford, IA

Agri-Powerl Computer Systems
Pendleton, OR

Ag-Ware, Inc.
Kearney, NE

Agway Farm Computer Systems,
Agway Data Services, Inc.
Syracuse, NY

Alfa Laval Agri, Inc.
Kansas City, MO

All Star Computer Service
Woodford, VA

American Business Analysis
Amarillo, TX

Argos Software
Fresno, CA

Arkansas Systems, Inc.
Little Rock, AR

Atlantis Software, Inc.
Spokane, WA

Babson Bros, Co.
Wheatridge, CO

Loren Bennett
Davis, CA

Blue Sky Software
Cotton, WA

Calvert Computer Systems, Inc.
Athena, OR

CAPA Software Corp.
Saskatoon, SK
S7H OV1 Canada

Center for Farm Management
St. Paul, MN

Chan's Easy System
Colome, SD

Cherrygarth Farms Software, Inc.
Auburn, IN

Chicago Mercantile Exchange
Chicago, IL

C-1-L Agventure
London, Ontaria
N6A 4L6 Canada

CISCO (Commodity Info. Services Co.)
Chicago, IL

Climate Assessment Technology, Inc.
Houston, TX

Computer Agri-Venture
Peguot Lakes, MN

Computer Friend
Quincy, IL

Computerized Service & Design
St. Onge, SD

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[36] Extensive, but not necessarily complete. Some companies leave the industry each year; mergers and buy-outs are currently under discussion.

Agri-Management Services, Inc.
Statham, GA

Compu Trac, Inc.
New Orleans, LA

Control Data Corporation
(See Doane Information Services)

Country Computing
Bridgeton, IN

Countryside Data, Inc.
Idaho Falls, ID

Crop Data Mgt. Systems
Maryvilie, CA

Cyber-Scan, Inc.
Buffalo, MN

Dairysoft Custom Software
La Jolla, CA

Dairy Solutions by MRB, Inc.
Zephyrhills, FL

Dalex Computer Systems, Inc.
Mound, MN

Data Management Assoc., Inc.
Shippensburg, PA

Datasphere Computer Systems, Inc.
Portland, OR

Decision Support Software, Inc.
McLean, VA

DHI Computing Service (DHI-Provo)
Provo, UT

D'Laubach
Carter, MT

Brubaker Software
Lafayette, IN

Dan DuPort & Associates
San Francisco, CA

Efficiency Resources, Inc.
Oakville, IA

EMS Software
Pleasant Grove, CA

Farm & Forest Software
White Bear Lake, MN

FarmComp
Logan, UT

F.A.R.M. Computer Consulting
Garfield, WA

Farm Credit Banks of Springfield
Farm Credit Banks of St. Paul
Farm Credit Bank of Baltimore
Springfield, MA

Farmer's Software Exchange Assoc.
Ft. Collins, CO

Farmhand Computer Systems, Ltd.
Mitchellville, IA

Farmhand Software, Inc.
Poolesville, MD

Farm Info. Services, Inc.
Waterproof, LA

Farm Management, Inc.
New Lenox, IL

F.A.R.M.S., Inc.
St. Johnsville, NY

Computer Power Unlimited
Bancroft, IA

FBS Systems
Aledo, IL

Fred's Micro-Ware
Amboy, MN

General Farm Services
Ithaca, NY

Great Plains Software
Fargo, ND

Bobby J. Hall & Associates
McComb, MS

Harvest Computer Systems
Alexandria, IN

HCI
Hutchinson, MN

Heizer Software
Concord, CA

Herd Management Systems, Inc.
San Antonio, TX

Hi-Plains Systems, Inc.
Amarillo, TX

Hobar Publications
St. Paul, MN

Holm-Dietz Computer Systems, Inc.
Fresno, CA

Holstein Association
Brattleboro, VT

J.B. Holter
Durham, NH

Homestead Computer Services, Ltd.
Winnipeg, Manitoba
R3T 1T6 Canada

HowardSoft
La Jolla, CA

D.R. Hutchinson Consultants
Houston, TX

ICM Computer Systems, Inc.
Wenatchee, WA

IlliNet Software, Univ. of IL
Urbana, IL

Illinois Farm Bureau
Bloomington, IL

In-TEC Equipment Co.
Dayton, OH

Integrated Controls Inc.
Milltown, NJ

Iowa Farm Business Assoc.
Ames, IA

Jones Agricomp Services, Ltd.
Calgary, Alberta TOM OEO Canada

Josalli, Inc.
Enka, NC

Lassen Software, Inc.
Paradise, CA

Livestock Technology Mgt.
Sycamore, IL

Market Master
Columbus, OH

MarketSoft
Chicago, IL

Marketview Software, Inc.
St. Charles, IL

Memory Systems, Inc.
Skokie, IL

Microstar Software Ltd.
Nepean, Ontario K2E 7J6 Canada

MicroVest
Macomb, IL

Modular Electronics, Inc.
St. Paul, MN

N-Squared Computing
Silverton, OR

Nutritional Software Systems
Elkhart, IN

Orange Software
Fresno, CA

PD Incorporated
Fairfield, CA

Pioneer Hi-Bred International, Inc.
Urbandale, IA

Post Rock Computing, Inc.
Luray, KS

Pro-Ag Software Co.
Luray, KS

Red River Computers
Fargo, ND

Red Wing Business Systems, Inc.
Red Wing, MN

Resource n Corporation
Carlisle, MA

Response, Inc.
Jackson, MN

Russell Associates
Le Sueur, MN

Sage Systems
Lovelock, NV

St. Benedict's Farm
Waelder, TX

Settler Computer Technologies, Inc.
Regina, SK S4N 5W5 Canada

Shoebox Computer Services
Danville, KS

Smith & Associates
St. Charles, IL

Software Techniques of Colorado, Inc.
Ft. Collins, CO

Specialized Data Systems, Inc.
Madison, WI

Valley Agricultural Software
Tulare, CA

Valley Computer Systems
Clovis, CA

Westfalia Systemat
Elk Grove, IL

Table II.4 **On-line Agricultural Information Services**

System Name	Sponsor	Primary Users	Type of Services
ACRES American Agric. Communications Sys. Park Ridge, IL	American Farm Bureau Federation	Members of 36 participating state farm bureaus	Info. retrieval, market data analysis and AgriVisor trading advice, weather, legislative developments, all USDA market reports.
agLine St. Louis, MO	Doane Information Services	Agricultural Computing newsletter subscribers	Electronic mail, ag software reviews, public domain ag software, cash commodity, futures, & options prices, market advice and analysis, major USDA reports, Washington reports.
Agribusiness U.S.A. Pioneer Hybrid Data Base Mgt. Johnston, IA	Pioneer Hi-Bred International, Inc.	Agribusiness	Indexes & abstracts from more than 300 business & gov't. publications, complete from Jan. '89 to present. Full text of USDA statistical reports. Updated every week.
AGRICOLA National Agricultural Library Information Systems Division Beltsville, MD	USDA/NAL	Farmers, agricultural researchers nationwide	Info. retrieval (primarily agricultural research), information and university Cooperative Extension publications.
AgriData Network Milwaukee, WI	AgriData Resources, Inc.	Nationwide	Business decision info.; Ag Ed Network, market advisories, cash & futures prices, gov't. commodity news.
AQS II Commodity News Services, Inc. Leawood, KS	Commodity News Services	Nationwide	Grain and livestock futures and cash prices, weather, and financial information.
ATI-Net Calif. Agricultural Technology Institute Calif. State University Fresno, CA	CATI	California farmers and nationwide	Info. on Calif. agriculture, public domain software, bulletin boards, electronic mail, teleconferencing.
DRAGNET Delaware Dept. of Agriculture Dover, DE	Delaware Dept. of Ag in cooperation with the University of Deleware Cooperative Extension	Delaware ag professionals	Bulletinboard, public domain farm mgt. & agronomic software for downloading.
EXNET Ames, IA	Iowa State University Extension Service	Iowa extension services and farmers	Integrated pest management, farm and home economics info., weather reports, electronic mail, USDA

F:2

			markets.
FACTS Ag Computer Network W. Lafayette, IN	Purdue University	Indiana farmers and extension offices	Ag data bases for Indiana, decision aid programs, problem solving programs, info. retrieval.
FAST Alachua, FL	FAST (Florida Agricultural Services and Technologies)	Southeastern farmers & horticulturists	National Weather Service data, updated every 30 min. Includes forecasts. IR tracking of hurricanes, severe thunderstorms.
Grassroots Winnipeg, Manitoba R3H OR9	Grassroots Information Services	North America-wide, mainly agricultural and financial	Market prices, stock market quotes, advice, & analysis, various reports & newsletters.
Instant Update Cedar Falls, IA	Professional Farmers of America, Inc.	Nationwide	Info. retrieval, commodity prices, market advice and analysis, commodity options, weather, news wire.
NPIRS User Services, NPIRS Entomology Hall, Purdue University West Lafayette, IN	Purdue University	Nationwide	Federal & state pesticide registrations, related chemical info., all hazardous chemicals, MSDS (Material Safety Data Sheets), EPA's PDMS (Pesticide Documentation Mgt. System).
SCAMP IPM Program NYS Agricultural Experiment Station Geneva, NY	Cornell University	New York extension offices, New York state agencies, coop. institutions, and farmers nationwide.	Info. retrieval, pest forecasting, weather forecasting, pest/crop/weather reporting, elec. mail. Macintosh IBM bulletin boards.
The Source McLean, VA	Source Telecomputing Corp.	Nationwide	Info. retrieval, commodity prices, USDA reports, electronic mail.
UMC BBS Columbia, MO	Univ. of Missouri-Columbia	Missouri and midwestern ag professionals	Utility programs, spreadsheets, daily & weekly info from Univ. of Missouri Columbia College of Agriculture on Prices, production practices, Integrated Pest Mgt., and Management decision aids and spreadsheet templates. Info from Soil Conservation Service/USDA, daily Missouri agriweather forecast.
USDA EDI Service U.S. Dept. of Agriculture Washington, D.C.Computer Systems House Salt Lake City, UT	USDA	Distributors of information to farmers & ranchers	USDA news releases, crop and livestock market, situation and outlook reports.

Figure III.2. Example of a data acquisition network for DSS

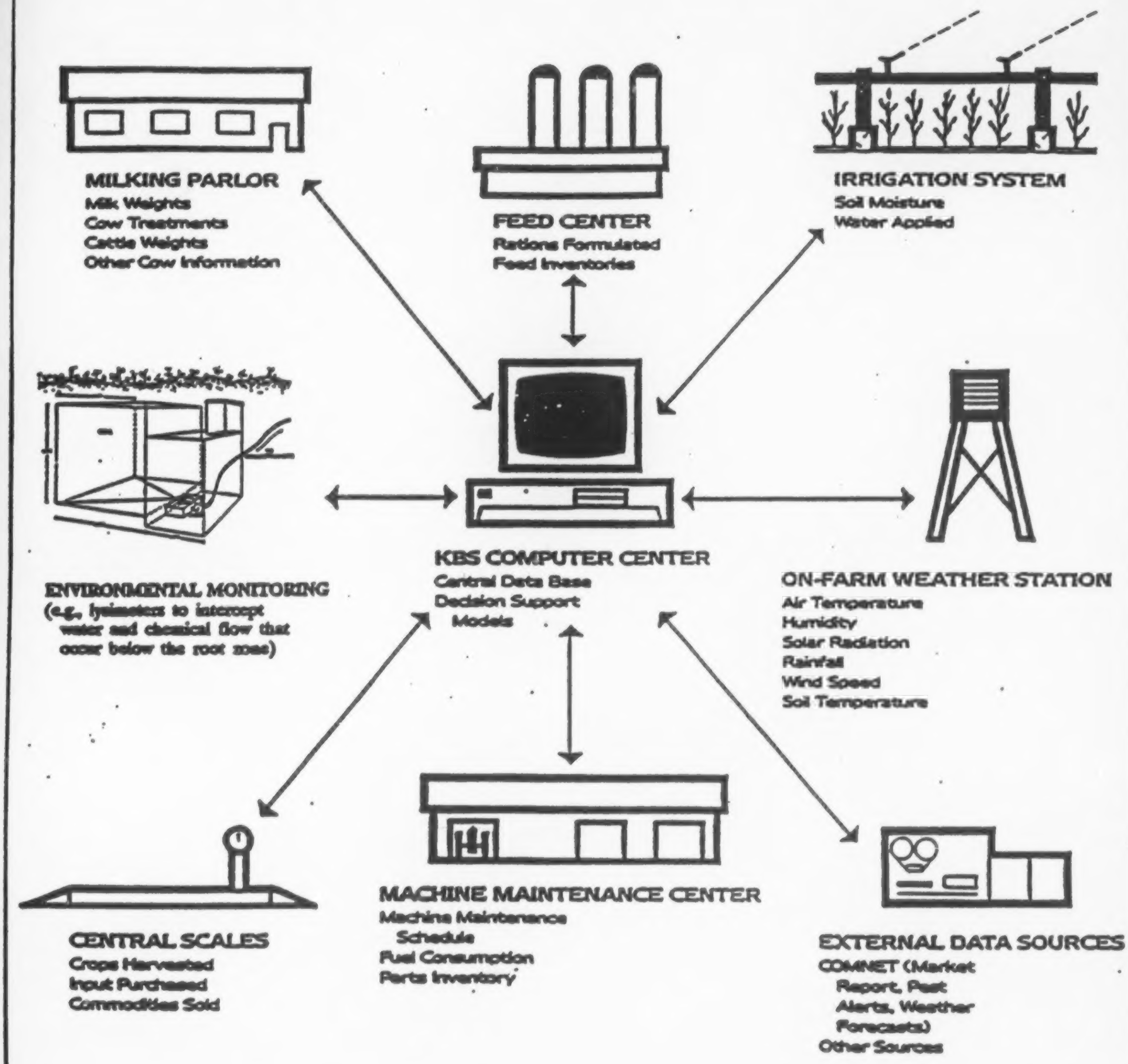
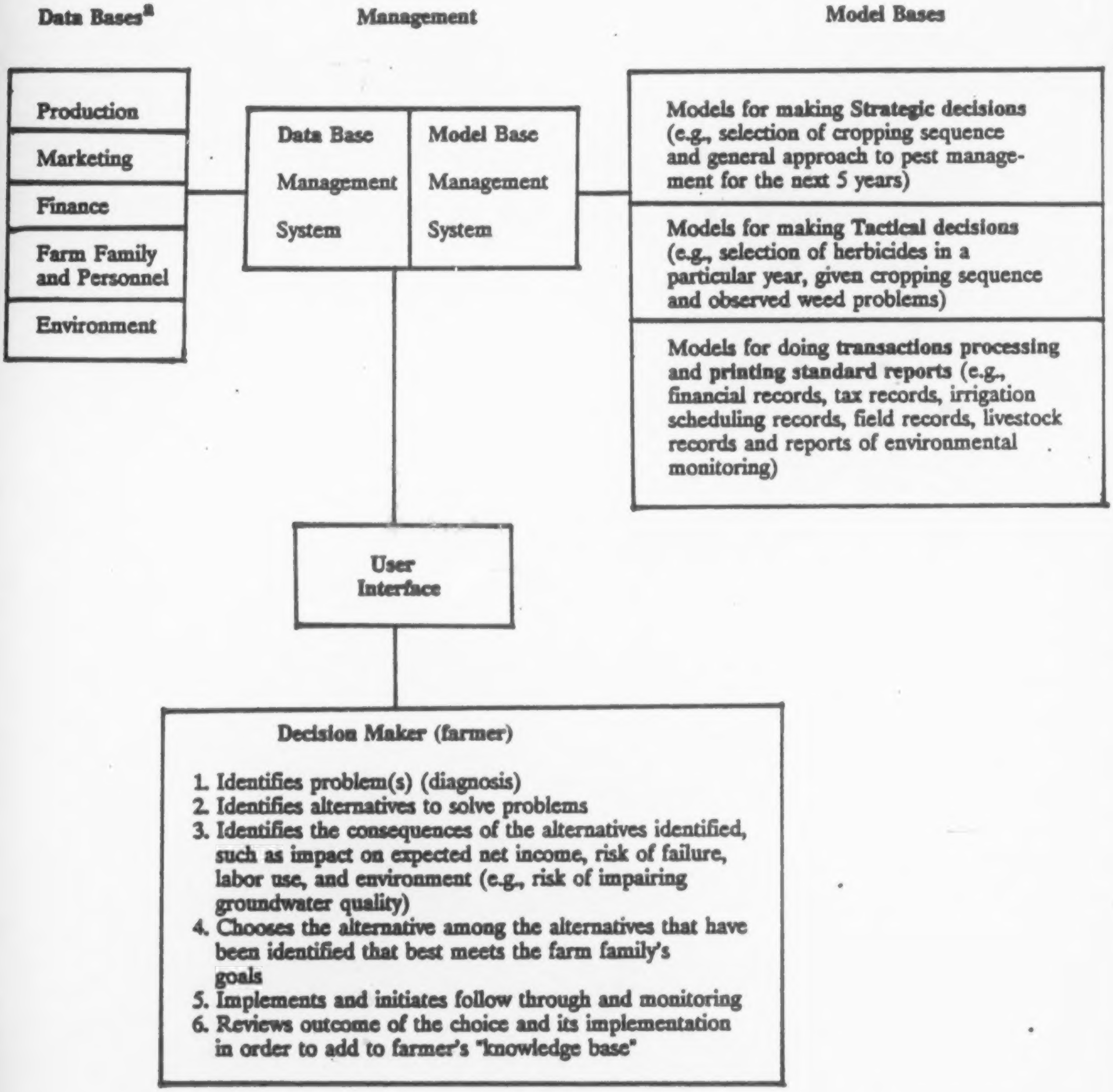


Figure III.1 Components of a Decision Support System



Models for making Strategic decisions (e.g., selection of cropping sequence and general approach to pest management for the next 5 years)

Models for making Tactical decisions (e.g., selection of herbicides in a particular year, given cropping sequence and observed weed problems)

Models for doing transactions processing and printing standard reports (e.g., financial records, tax records, irrigation scheduling records, field records, livestock records and reports of environmental monitoring)

Decision Maker (farmer)

1. Identifies problem(s) (diagnosis)
2. Identifies alternatives to solve problems
3. Identifies the consequences of the alternatives identified, such as impact on expected net income, risk of failure, labor use, and environment (e.g., risk of impairing groundwater quality)
4. Chooses the alternative among the alternatives that have been identified that best meets the farm family's goals
5. Implements and initiates follow through and monitoring
6. Reviews outcome of the choice and its implementation in order to add to farmer's "knowledge base"

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[a] Data bases contain data that relate to the farm (internal data) such as information contained in a crop field record system *and* are external to the farm such as information on pesticides the grower is considering using.

Figure III.3a Irrigation Scheduling Prototype Model: Components of Model Input

```
Irrigation Sch. Prog.     (Ver. 1.0BT)    Time: 17:37:10  Date: 07/15/89    Page

            MICHIGAN STATE UNIVERSITY IRRIGATION SCHEDULING PROGRAM
===============================================================================
Precipitation and Soil Moisture Record               Latitude: 42d44m  Longitude: 84d2
Farm: Black OTA Farm                        Field: Center Pivot            Crop: Corn
-------------------------------------------------------------------------------
       Wthr   Mean    Crop ET  Rain  Irrig.  Deplet.  PMC    PM Graph      M=60%
Date   Type Temp.(F)  ----------- Inches -----------   %  0             M
-------------------------------------------------------------------------------
Jun 22  Act    73      .23                     .90     76  +++++++++++|+++
Jun 23  Act    69      .21                    1.11     70  +++++++++++|++
Jun 24  Act    66      .19                    1.30     65  +++++++++++|+
Jun 25  Act    68      .21                    1.51     60  +++++++++++|
Jun 26  Act    71      .22          1.50       .23     93  +++++++++++|++++++
Jun 27  Act    67      .20                     .43     88  +++++++++++|+++++
Jun 28  Act    67      .19    2.40            -.19    104  ***********|*******
Jun 29  Act    65      .19                     .01     99  +++++++++++|+++++++
Jun 30  Act    67      .21                     .21     94  +++++++++++|++++++
Jul 1   Act    64      .19                     .40     89  +++++++++++|+++++
Jul 2   Act    64      .19                     .60     84  +++++++++++|++++
Jul 3   Act    67      .21                     .81     78  +++++++++++|+++
Jul 4   Act    68      .21                    1.01     73  +++++++++++|++
Jul 5   Act    72      .21                    1.22     67  +++++++++++|+
Jul 6   Act    68      .21          1.50      -.07    101  ***********|*******
Jul 7   Act    68      .21                     .15     96  +++++++++++|+++++++
Jul 8   Act    69      .22                     .37     90  +++++++++++|++++++

Total Season
to Date      814GDD   7.53    5.40  4.50
```

Legend:

Act = Actual input data vs. 'projected' input data

ET = Evapotranspiration

Rain = Inches of moisture supplied by rainfall

Irrig = Inches of moisture supplied by irrigation

Deplet. = Inches of moisture the soil is away from being saturated

PMC = Moisture, percent of field capacity

M = Target moisture, as a percentage of field capacity, at which irrigation is initiated

PM Graph = Moisture, percent of field capacity.

Irrigation Scheduling Prototype Model: Components of Model Output

recipitation and Yield Record
arm: Black OTA Farm

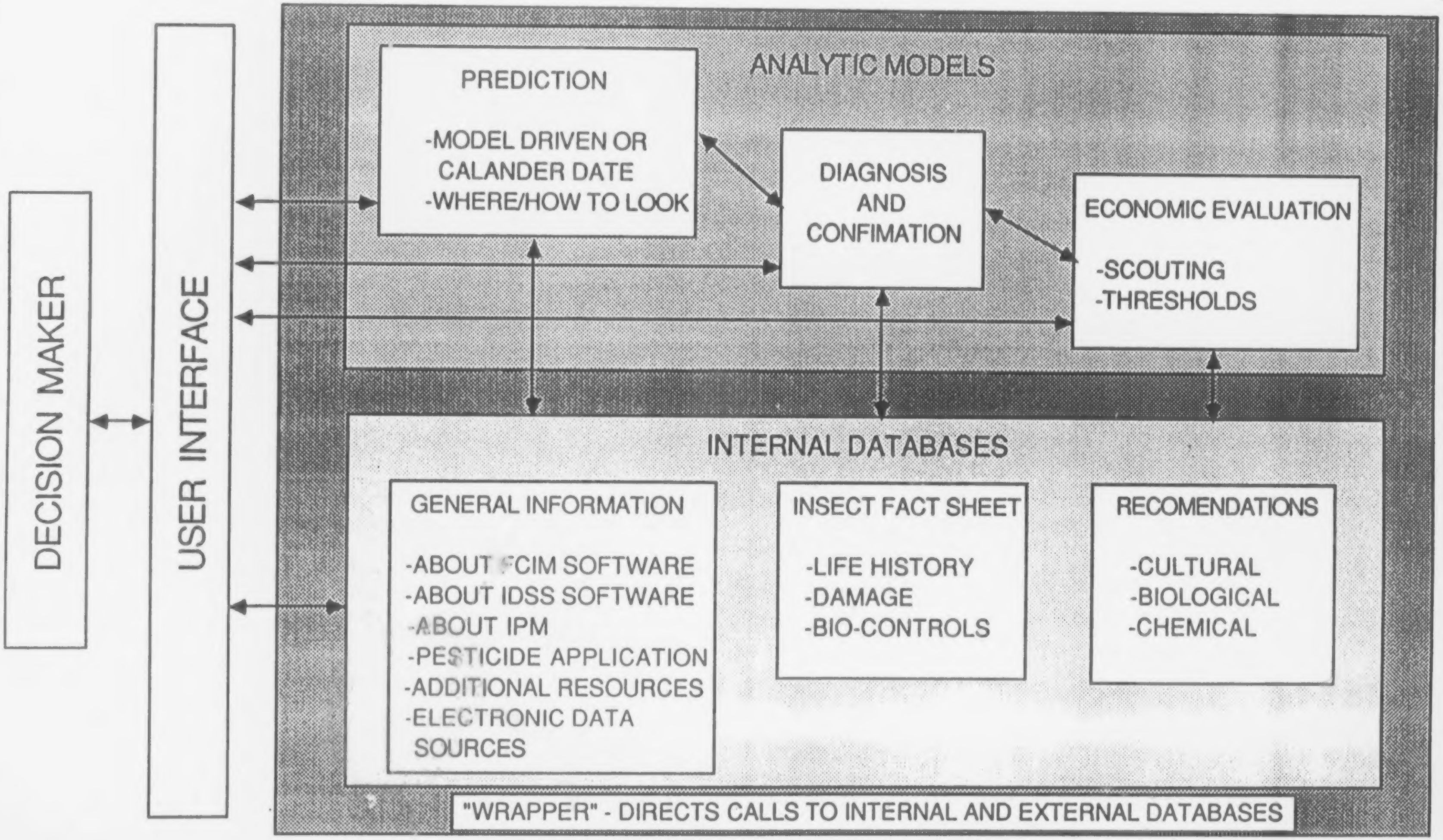
Latitude: 42d44m Longitude: 84d29m
Field: Center Pivot
Crop: Corn

te	Wthr Type	Rainfall Inches	Irrigation Inches	Drainage Inches	N Leaching Index	PMC %	Yield bu/A
22	Act					76	180.0
23	Act					70	180.0
24	Act					65	180.0
25	Act					60	180.0
26	Act		1.50			93	180.0
27	Act					88	180.0
28	Act	2.40		1.78	**	104	180.0
29	Act					99	180.0
30	Act					94	180.0
1	Act					89	180.0
2	Act					84	180.0
3	Act					78	180.0
4	Act					73	180.0
5	Act					67	180.0
6	Act		1.50	.07	*	101	180.0
7	Act					96	180.0
8	Act					90	180.0
Season ate		5.40	4.50	3.11			

N Leaching Index = Index of nitrogen getting below the root zone.

BEST AVAILABLE COPY

FIELD CROPS INSECT MANAGEMENT (FCIM) SOFTWARE



DECISION MAKER

USER INTERFACE

ANALYTIC MODELS

PREDICTION

-MODEL DRIVEN OR CALANDER DATE
-WHERE/HOW TO LOOK

DIAGNOSIS AND CONFIMATION

ECONOMIC EVALUATION

-SCOUTING
-THRESHOLDS

INTERNAL DATABASES

GENERAL INFORMATION

-ABOUT FCIM SOFTWARE
-ABOUT IDSS SOFTWARE
-ABOUT IPM
-PESTICIDE APPLICATION
-ADDITIONAL RESOURCES
-ELECTRONIC DATA SOURCES

INSECT FACT SHEET

-LIFE HISTORY
-DAMAGE
-BIO-CONTROLS

RECOMENDATIONS

-CULTURAL
-BIOLOGICAL
-CHEMICAL

"WRAPPER" - DIRECTS CALLS TO INTERNAL AND EXTERNAL DATABASES

E'2

Figure IV.1 Groundwater Contamination by Nitrate

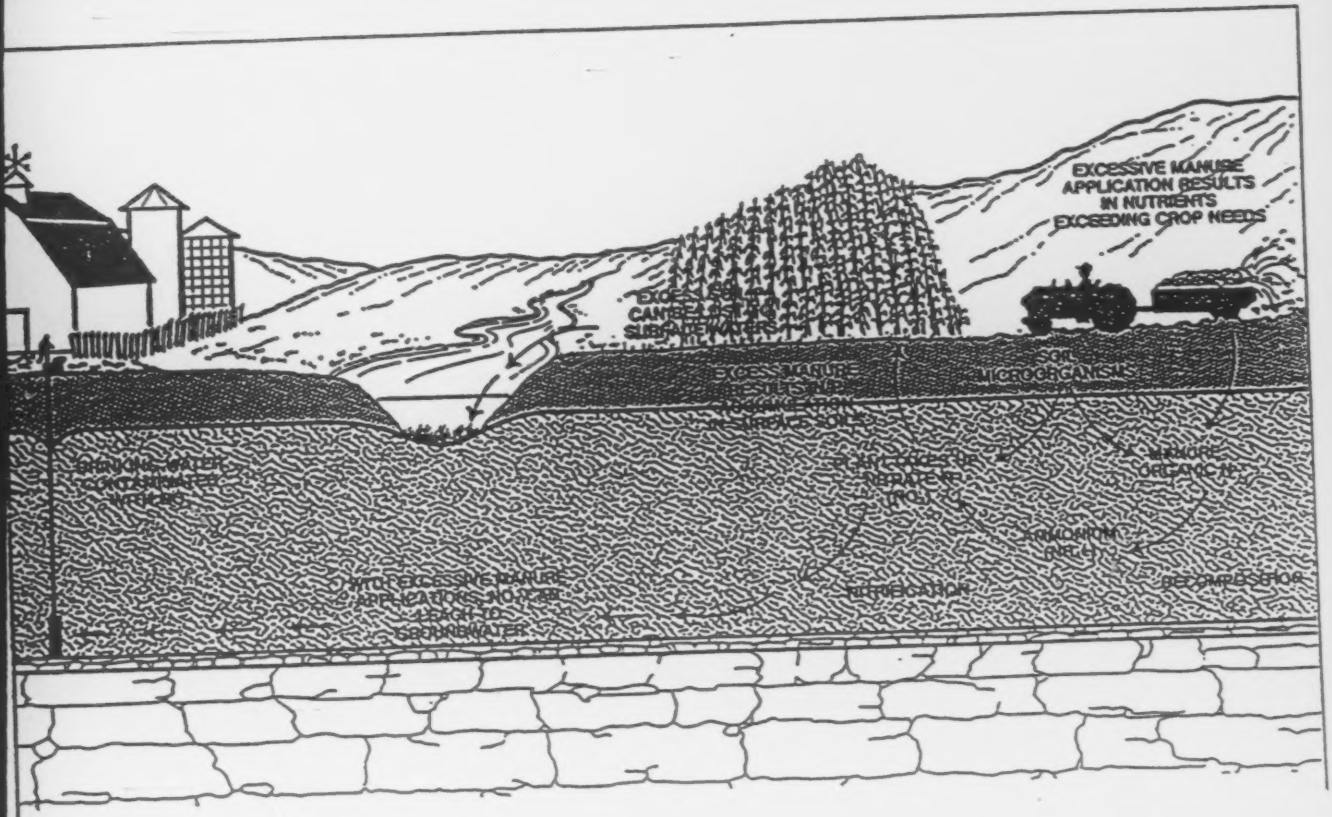
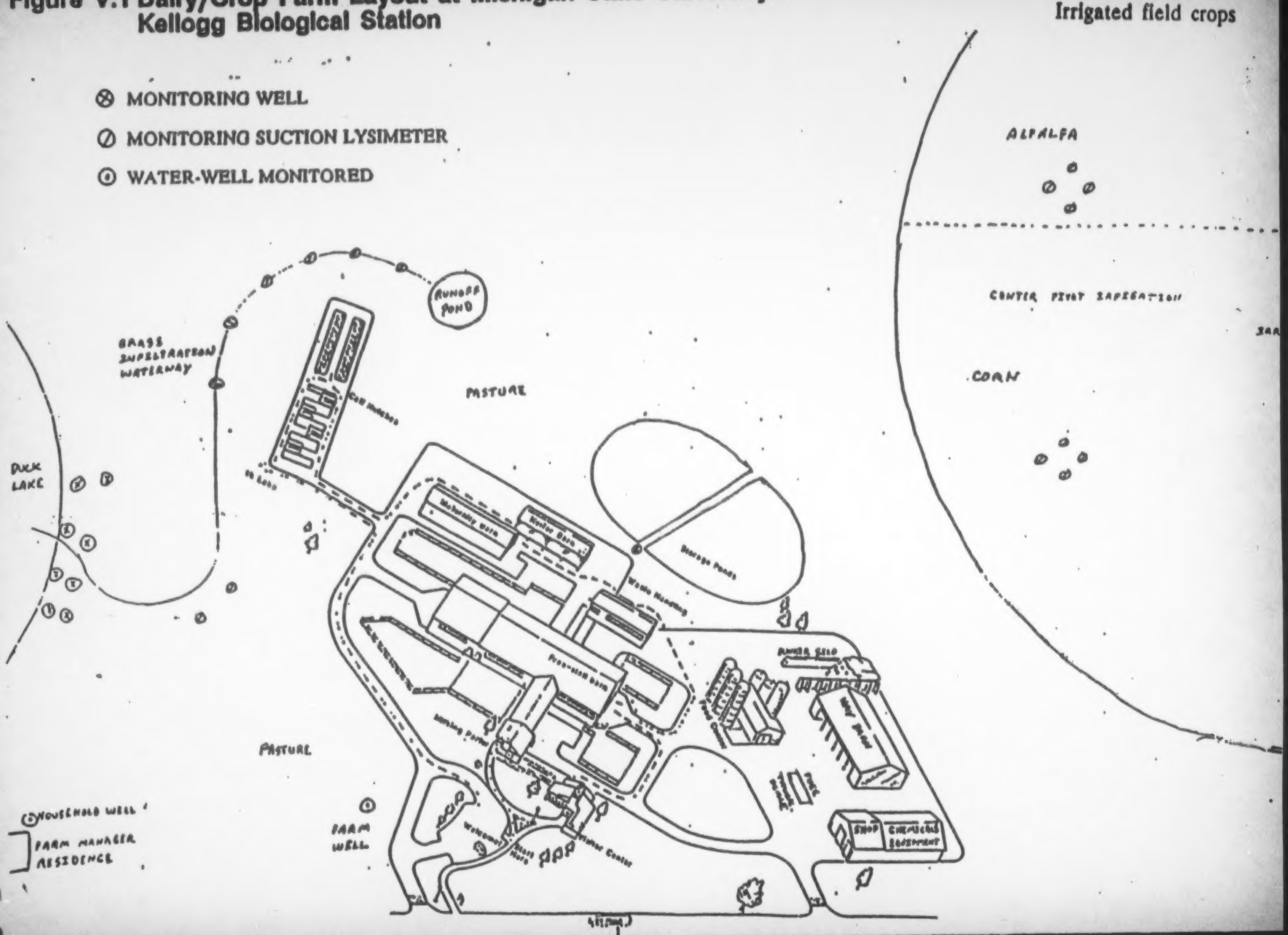

EXCESSIVE MANURE APPLICATION RESULTS IN NUTRIENTS EXCEEDING CROP NEEDS
SOIL MICROORGANISMS
MANURE ORGANIC N
AMMONIUM
NITRIFICATION
DECOMPOSITION
WITH EXCESSIVE MANURE APPLICATIONS, NO3 CAN LEACH TO GROUNDWATER
DRINKING WATER CONTAMINATED WITH NO3

Figure V.1 Dairy/Crop Farm Layout at Michigan State University's Kellogg Biological Station



E. 2

Figure V.2 FATE OF ORGANIC CHEMICALS

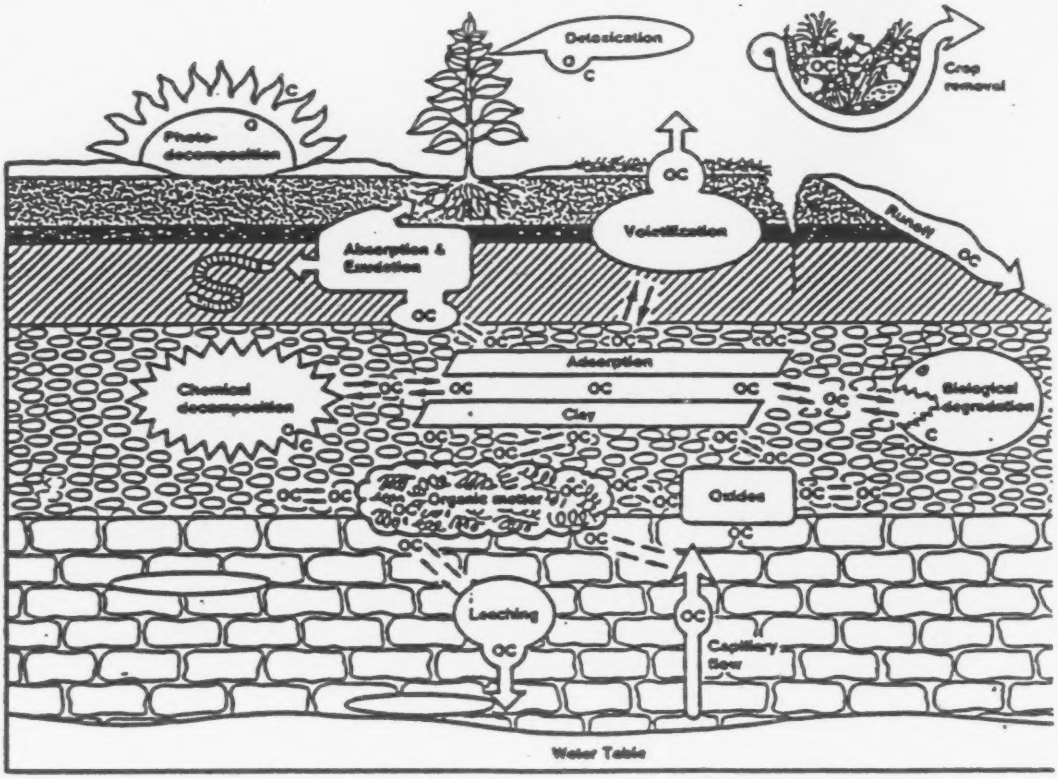
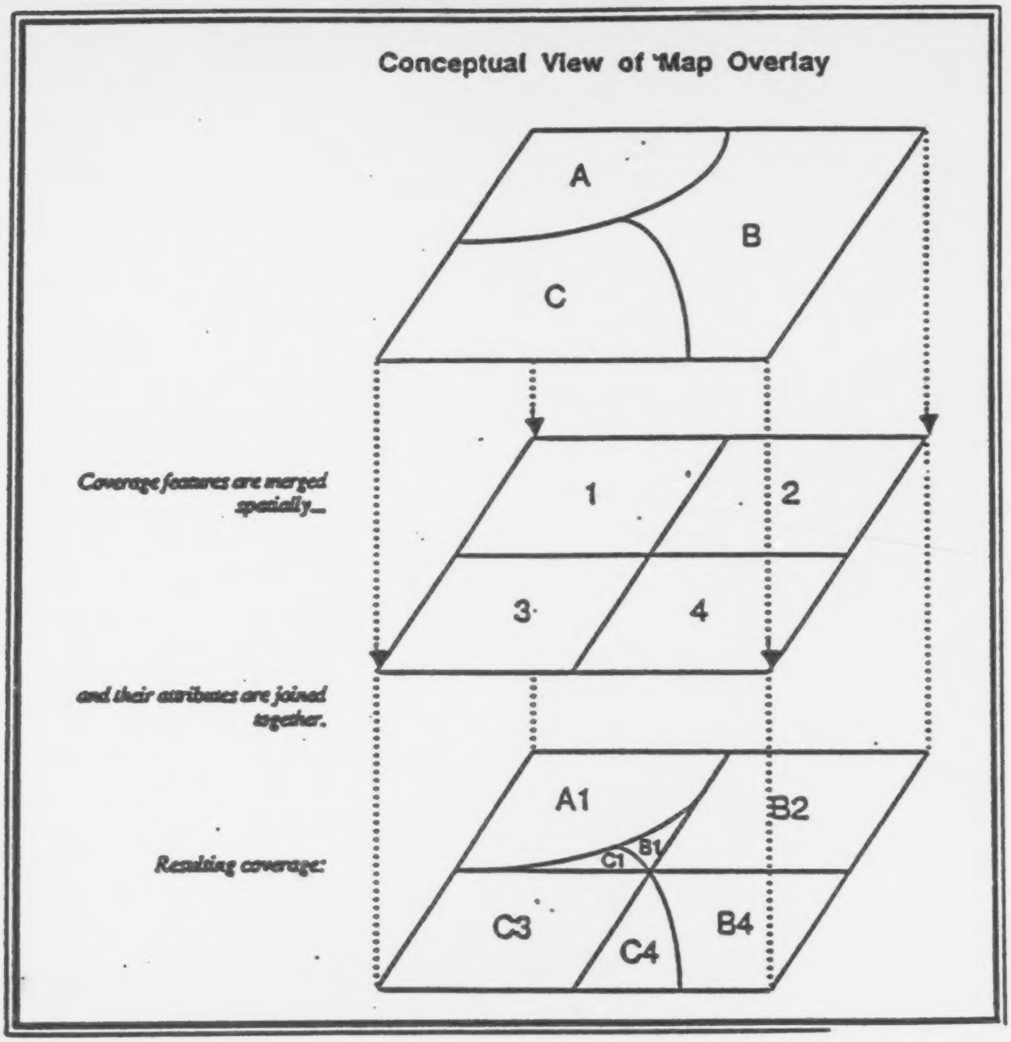


Figure A.1 GEOGRAPHIC INFORMATION SYSTEMS: CONCEPTUAL DIAGRAM


Conceptual View of Map Overlay
A
B
C
Coverage features are merged spatially...
1
2
3
4
and their attributes are joined together.
Resulting coverage:
A1
B2
C1
B1
C3
B4
C4

Under GIS, images at different levels of detail (e.g., watershed, farm, field) and for different attributes (e.g., soil type, previous crop, acquifer, soil characteristics which determine risk of pollution by ...) can be "pulled up" to the computer screen individually and/or overlayed. For example, for the 1st factor in our example, there are 3 subdivisions: A, B, and C. For the 2nd factor, there are 4 subdivisions: 1, 2, 3, 4. When factor 1 is overlayed on factor 2, there are 7 subdivisions: A1, B1, B2, B4, C1, C3 and C4.

Figure A.2 APPLICATIONS TO POTATO PRODUCTION

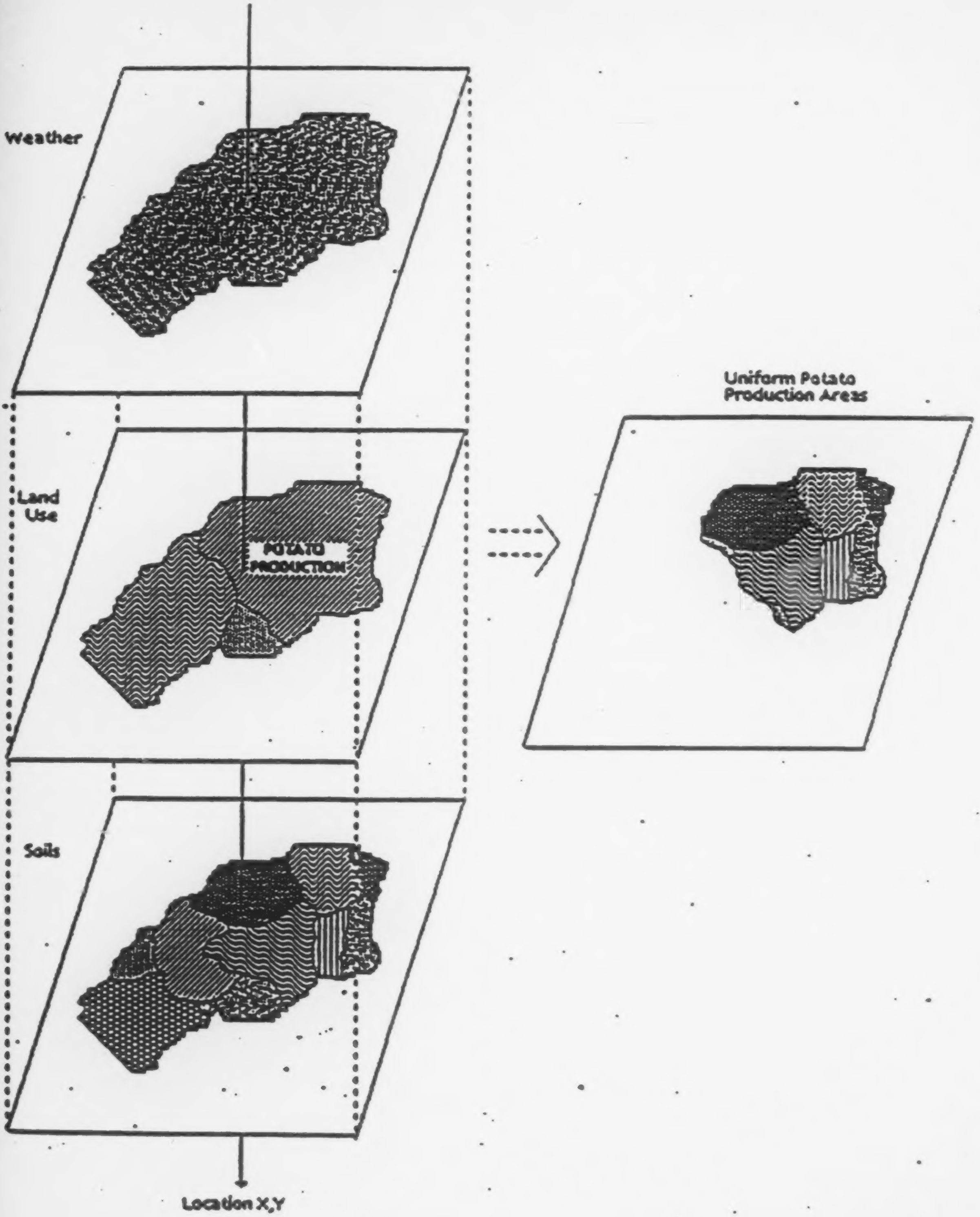


Figure A2 considers three factors: weather, land use, and soils. The resulting summary depicts the resultant combinations of each of these factors.

GLOSSARY

Algorithm: A computational procedure for performing a specified task, such as sorting a set of names into alphabetical sequence.

Artificial intelligence: The branch of computer science that deals with the use of a computer to perform humanlike functions, such as diagnosis. See also Expert System.

Data: Numeric values, textual characters, and graphic images, generally retained in the database in raw form prior to processing into information for operational or decision making purposes.

Data entry: The function that deals with the input and editing of data entering the transaction processing system or other components of a DSS program being used in interactive mode.

Database: The collection of machine-readable data maintained as part of a management information system; the collection of data described by the system's data dictionary.

Database management system: A system software product that provides a variety of functions needed to access, maintain, and protect the organization's database.

Decision support system: A computer-based system designed to assist a decision maker (, farm family) to make better, faster, or cheaper decisions.

Dynamic geo-referencing: A process using remote sensing devices to provide the real time location of any entity in three dimensions. Current capabilities (satellites, signal transmitters, etc.) can provide location within centimeters.

Electronic mail: The transmission of text (or possibly images) in interpersonal communication over a telecommunications network, allowing either a simultaneous conversation or (more typically) message storage with delayed retrieval on demand.

Expert system: A branch of artificial intelligence that deals with complex decision processes defined in terms of a series of rules that mimic a human expert.

External storage device: A data storage device that permits the computer to read stored data into its main memory (where all computation takes place) and write the results of computations back into the device; magnetic disk and tape are currently by far the most widely used forms of external storage.

Geographic information system (GIS): A system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth.

Requisite functionality for a GIS consists of: (1) the ability to create, edit, and delete geographically structured data; (2) the ability to link locational and attribute data; (3) the ability to perform spatial analysis functions, including analytical map overlay of multiple data themes and network analysis; (4) the ability to display geographic information. Geographic data editing and network analysis are both facilitated by use of a topological data structure that describes objects as points, lines, and areas and records the relationships of incidence and connectivity among them.

Information: Processed data used for decision making; a representation of reality, often in condensed form, that reduces the uncertainty about the true state of nature.

Integrated system: A system having tight coupling and/or extensive resource sharing among its component parts.

Interactive system: A system that provides a close dialogue between a human and a computer, with the human issuing commands or posing questions and the computer responding appropriately (usually within a few seconds or even a fraction of a second).

Interface: The boundary between two subsystems that interact with one another, or between a human and a computer system.

Land information system: A geographic information system having, as its main focus, data concerning land records.

Layer: A conceptual grouping of data types that share common characteristics. Syn: theme.

Local area network: A telecommunications network used to link devices (computers, printers, etc.) within a relatively small geographic area (generally within a radius of one kilometer).

Lysimeter: (i) A device for measuring percolation and leaching losses from a column of soil under controlled conditions; (ii) A device for measuring gains (precipitation and condensation) and losses (evapotranspiration) by a column of soil)

Magnetic disk: A direct access storage medium for storing files and other parts of the database, in which data are recorded magnetically on a revolving disk.

Magnetic tape: An external sequential access storage medium, generally used for storing large sequential files, backup files, and archival data.

Mainframe: A powerful computer, almost always linked to a large set of peripheral devices (disk storage, printers, etc.), and used in a multipurpose environment at the corporate or major divisional level.

Management information system (MIS): A computer-based information system used in the operational management and decision making of an organization.

Menu: A list of alternative actions or data values presented on a display screen to allow a user to select among the proposed options during a dialogue with the computer.

Microcomputer: A small, relatively inexpensive computer, usually dedicated to use by a single user; a personal computer or workstation.

Minicomputer: A medium-sized computer, usually serving a relatively small organizational unit or dedicated to a fairly narrow specialized task.

Model: A mathematical or symbolic representation of real-world environment, used to predict the consequences of alternative courses of action in order to choose the best alternative.

Neutron probe: A device which measures biometric soil water content.

Off-line storage: Data storage not connected automatically to a computer; storage that requires human intervention in order for the computer to access the data.

On-line storage: Data storage connected to a computer in a way that permits automatic access to the data without any human intervention.

Operating system: A basic system software product for automatically managing the operations of a computer, which deals with such matters as controlling access to the computer, setting priorities among multiple users, allocating computer resources, and handling input/output operations; often termed the "traffic cop" of the system.

Optical disk: A direct access storage medium in which data are recorded on a revolving disk in a form that can be sensed by optical means (e.g., photoelectric sensing of reflected laser-generated light). The principal advantage of such storage is its ability to store a very large volume of data in dense form and at low cost; the principal disadvantages are its relatively slow access time and (in some applications) the nonerasability of the medium.

Optical scanning: The use of an optical sensor to read input data.

Personal computer: A microcomputer (or workstation) dedicated to a single user at a time.

Program: A set of statements or instructions in a computer language that is intended to accomplish a specified task when executed on a computer (possibly after first being translated into machine-language form); to create a program.

Prototype: An interim application program, generally with less than 'full blown' capabilities, which is implemented relatively quickly and at low cost to demonstrate a functional capability, provide an unambiguous functional specification, serve as a vehicle for organizational learning, and (possibly) evolve ultimately into a fully implemented version.

Real-time process: A physical process in which control is exercised by a computer system within the (generally short) time span needed to take corrective action and maintain stability of the process.

Sensor: A device that responds to a physical stimulus (e.g., electrical conductivity, heat, light, pressure, a particular motion, or sound) and transmits a message to a controller (regulator) computer for use in evaluating whether a process is on target vs. whether inputs need to be modified.

Simulation: Use of the computer to mimic the operation of a physical process to analyze its behavior under alternative conditions, often with the objective of searching for a set of decision variables that lead to satisfactory or even near-optimum performance.

Software: A collective term for computer programs.

Software engineering: A set of disciplined methodologies for improving the reliability and lowering the cost of developing and maintaining computer software.

System: An entity composed of interacting subunits that have a common purpose or set of global goals.

Turnkey system: A complete system ready for operation (requiring the user merely to "turn on the key"), including hardware, system software, and application programs.

Updating: Changing the database to reflect all of the consequences of a transaction.

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